Requirements Analysis and Verification for the Thirty Meter Telescope with OpenMBEE and the OpenSE Cookbook

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Outline

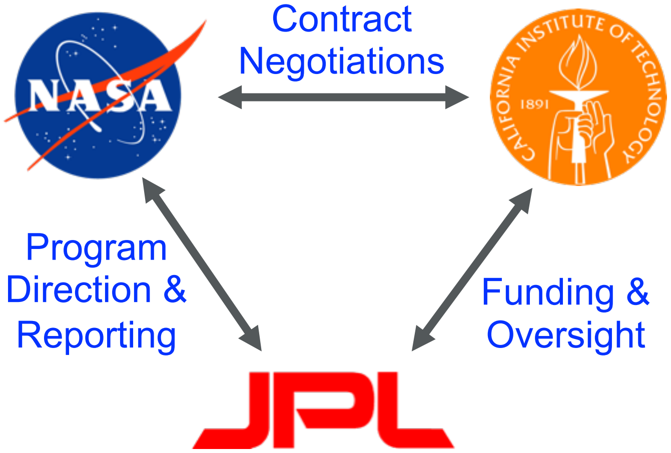
➡ Introduction
- Thirty Meter Telescope Project (TMT) and MBSE
- OpenSE Cookbook
- TMT Requirements Verification
- JPL Systems Environment
- Summary & Conclusions

Who is Robert?

- CAE Project Systems Engineer at NASA’s JPL - USA
- Member of INCOSE
- Formerly Control System/Software Engineer and Architect at:
  - European Southern Observatory – Germany, Chile
  - CERN – Switzerland/France
  - Siemens Healthcare - Austria
- M.Sc. Computer Science (Austria)

NASA Jet Propulsion Laboratory (JPL)

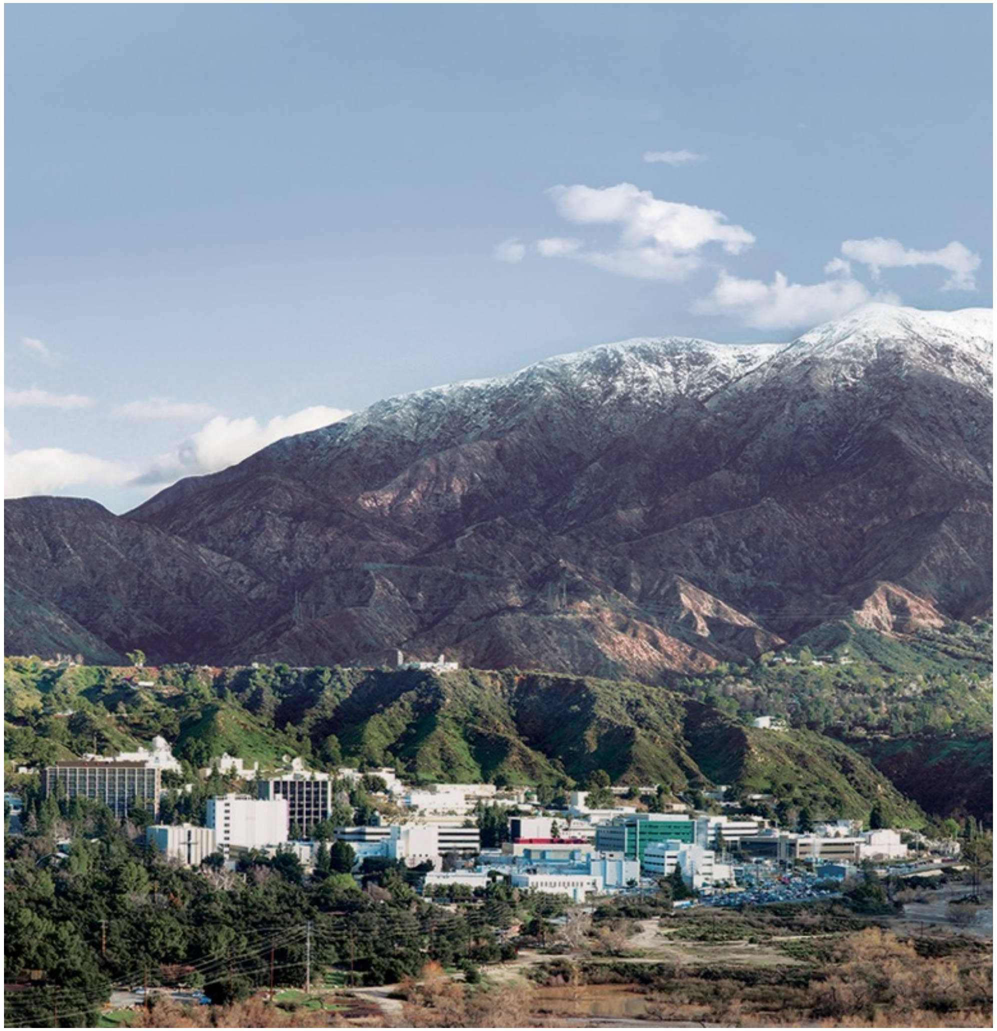
- Located in Pasadena, CA
- NASA-owned *”Federally-Funded Research and Development Center”*
- University-operated
- ~5,000 employees



Contract Negotiations

Program Direction & Reporting

Funding & Oversight



You May Know Some of Our Missions…

Voyager 1 & 2 (1977)

JPL’s Mission is Robotic Exploration

Mars Science Laboratory (2012)

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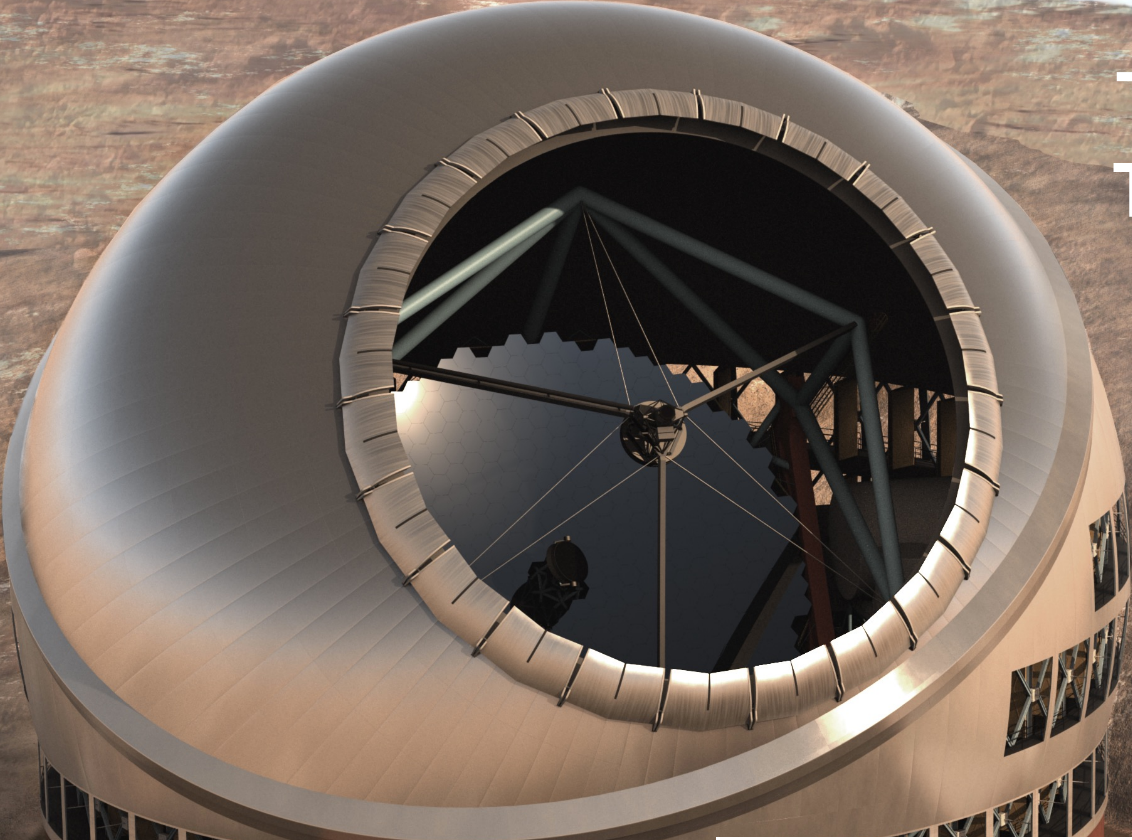
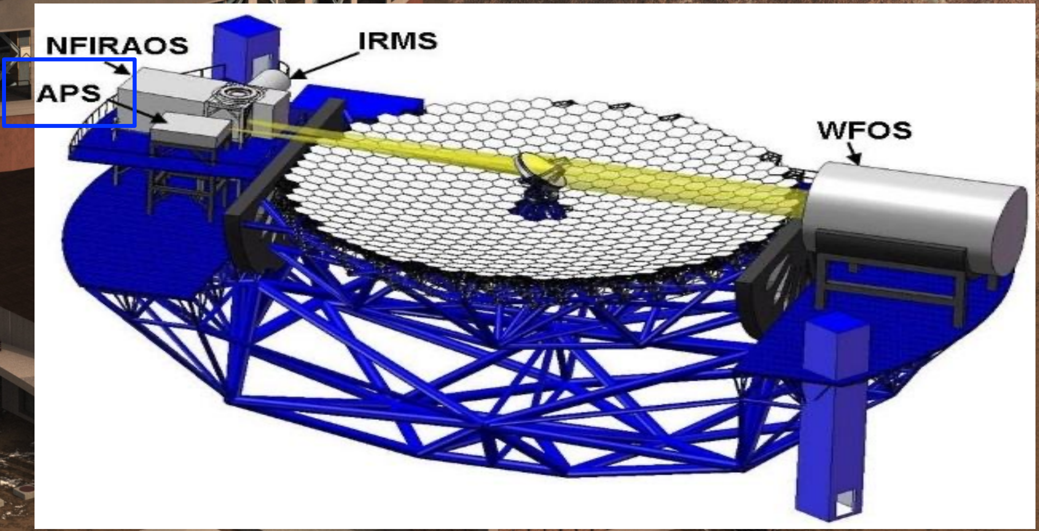
The Thirty Meter Telescope (TMT) Project

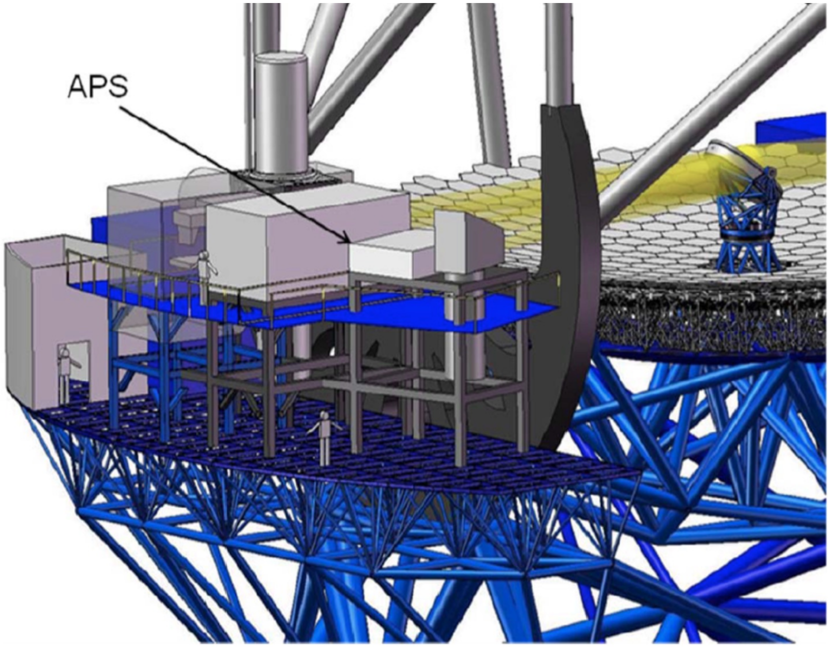




www.tmt.org

Alignment and Phasing System (APS)

- Alignment and diagnostic instrument located on a Nasmyth platform
- Modified Shack-Hartmann wavefront sensor
- Responsible for pre-adaptive optics wavefront quality
- Uses starlight to measure wavefront errors and determine commands to send for aligning optics



TMT applies "Hybrid" Systems Engineering Approach

Traditional SE

- Clear, defined deliverables
- Easily accessible
- Shallow learning curve
- Simple traceability

MBSE

- Understanding behaviors of a system
- "Rich" capability to represent complex systems

Exploit the advantages of each approach

Model Based Systems Engineering

- MBSE is the formalized application of modeling techniques to support system requirements, design, analysis, verification, validation and documentation activities
- MBSE expresses a system using a Systems Modeling Language (SysML), a profile of UML
- MBSE is often applied with a method like Object Oriented System Engineering Method (OOSEM)
- OOSEM maps onto the ISO systems engineering process and integrates top-down (**functional decomposition**) approach with **model-based** approach

TMT MBSE Objectives

- Define an **executable SysML model**
- Use the model to **analyze the system design and verify requirements** on power consumption, mass, duration, pointing errors, …
- Produce **engineering documents**
  - Requirement Flow Down Document
  - Operational Scenario Document
  - Design Description Document
  - Interface Control Documents
- Use **standard languages and techniques, and COTS tools where practical** to avoid custom software development

Applications of MBSE with SysML at JPL

- JPL is already applying MBSE practice in a wide variety of projects, across a number of lifecycle phases
  - Planned mission to Europa / Europa Clipper
  - Mars 2020 (next Mars Rover)
  - InSight
  - Thirty Meter Telescope
  - Ground system development
  - Mars Sample Return
  - Cyber security
  - ...

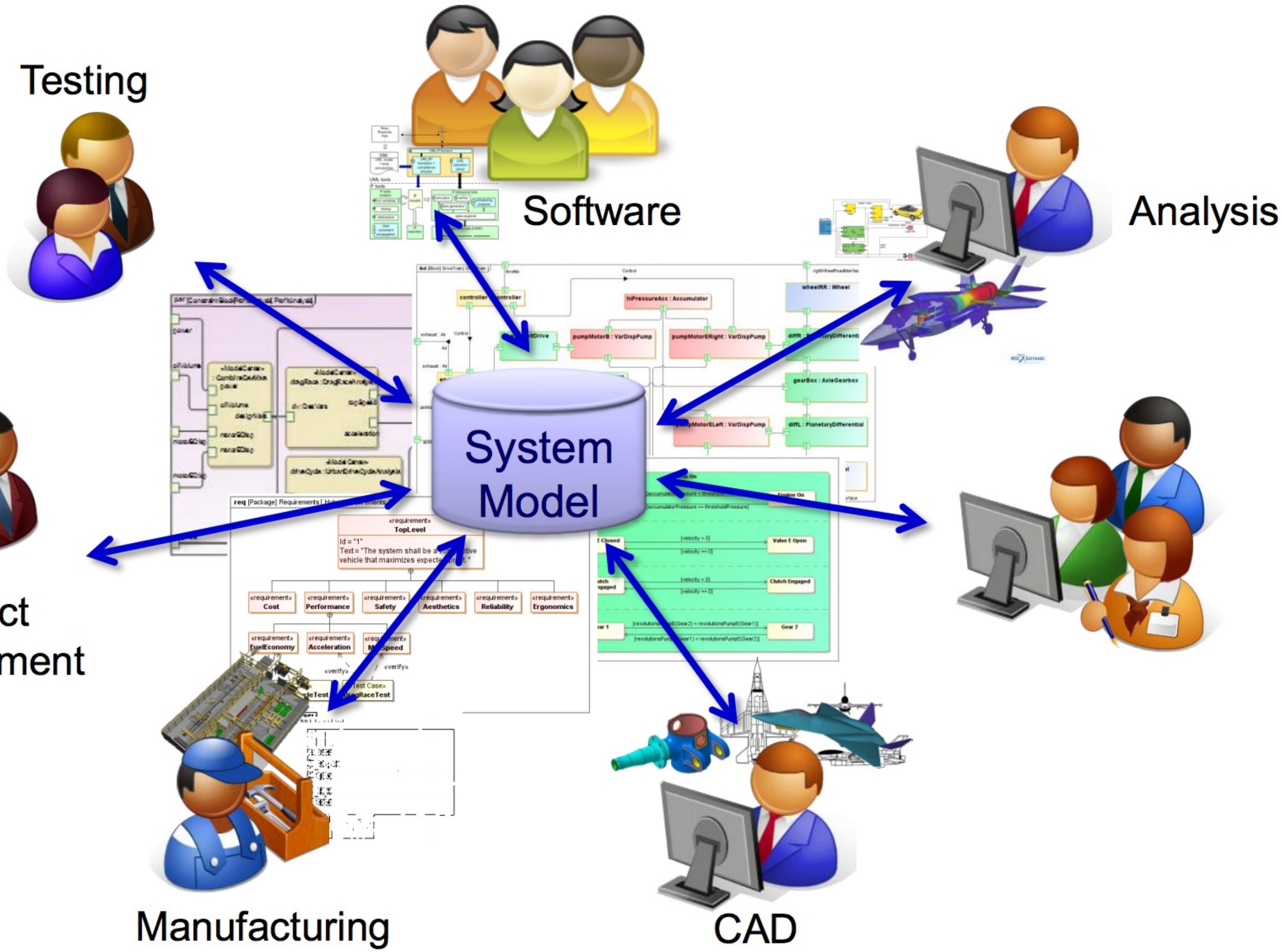
Not just spacecraft missions! Not just early phases of design!

- MELs, PELs, resource allocation and analysis, system decomposition, libraries / capturing reusable models, etc.

  → **We use MBSE to do SE**

MBSE is Much More Than Just Applied SysML

Information Management Across All Disciplines and the Life Cycle



Source: Paredis, 2012

TMT MBSE follows a well defined Modeling Approach

- Object-Oriented Systems Engineering Methodology (**OOSEM**), but with additional activities focusing on building an executable model
- Use case driven model development
- Challenges:
  - JPL is a **supplier** for a number of subsystems of the TMT (the **customer**)
  - Model is used by a number of teams, including TMT

ESEM = OOSEM + Executability

Executable SE Approach focuses on Key SE Artifacts

- Emphasize executable models to enhance understanding, precision, and verification of requirements
- Executable Systems Engineering Method (**ESEM**) augments the OOSEM activities by enabling executable models
  - ESEM defines executable SysML models that verify requirements
  - Includes a set of analysis patterns that are specified with various SysML structural, behavioral and parametric diagrams
  - Also enables integration of supplier/customer models and analysis

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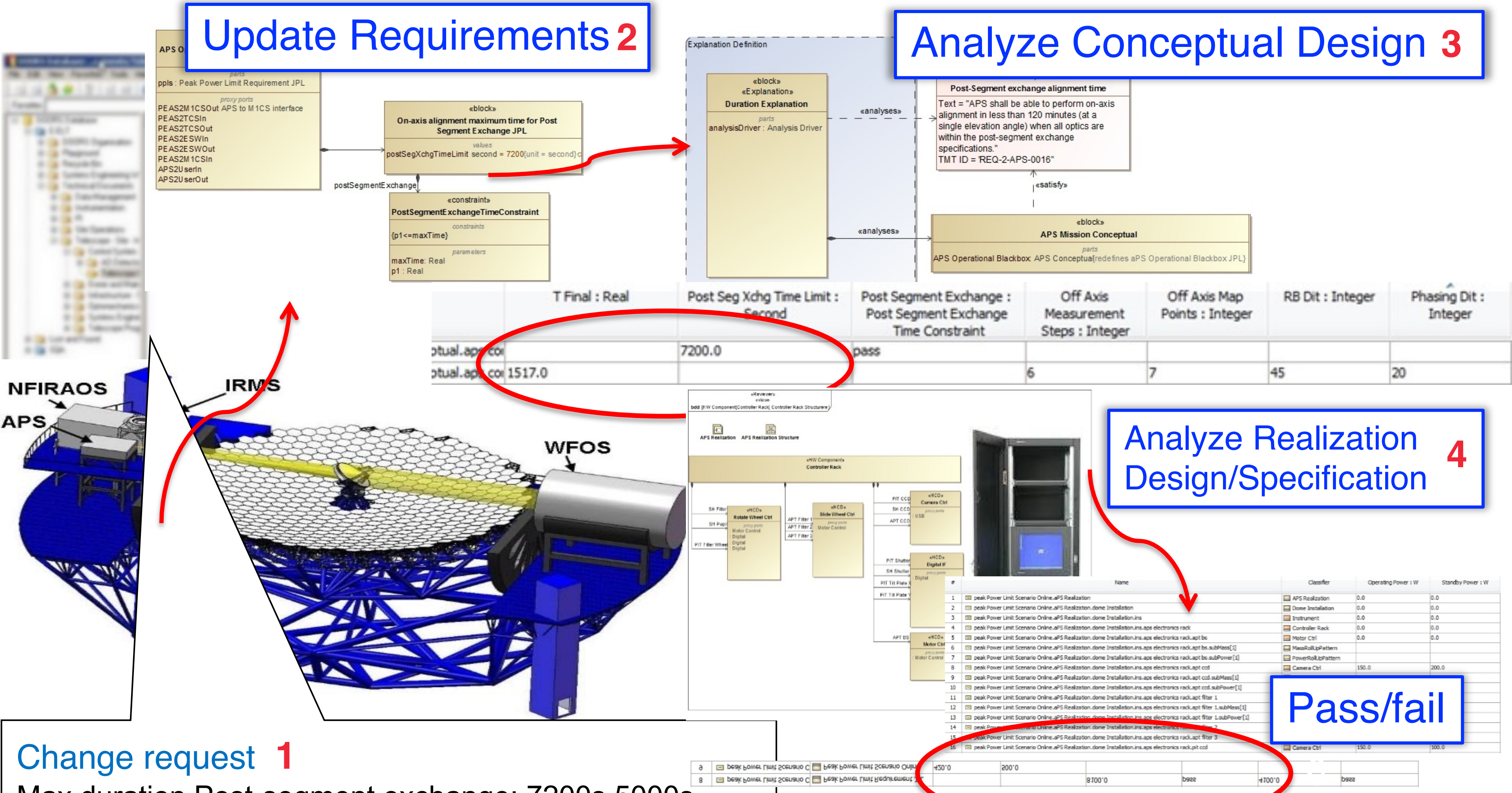
OpenSE Cookbook addresses Systems Engineering Concerns

- Provides goal oriented guidance using patterns, e.g.
  - How-to Verify Requirements
  - How-to Roll-up Technical Resources
- Driven by Systems Engineering Workflows
- Enables combining patterns into more complex recipes
- Demonstrates how to build system models with available tooling - How/where do I start?
- Includes known usages in TMT production model as reference
- Commoditizes Executable Systems Engineering

TMT Analysis workflows drive the OpenSE Cookbook



Update Requirements 2

APS O…
parts
ppls : Peak Power Limit Requirement JPL
proxy ports
PEAS2M1CSOut APS to M1CS interface
PEAS2TCSIn
PEAS2TCSOut
PEAS2ESWIn
PEAS2ESWOut
PEAS2M1CSIn
APS2UserIn
APS2UserOut

«block»
On-axis alignment maximum time for Post Segment Exchange JPL
values
postSegXchgTimeLimit second = 7200{unit = second}

postSegmentExchange

«constraint»
PostSegmentExchangeTimeConstraint
constraints
{p1<=maxTime}
parameters
maxTime: Real
p1 : Real

Analyze Conceptual Design 3

Explanation Definition

«block»
«Explanation»
Duration Explanation
parts
analysisDriver : Analysis Driver

«analyses»

Post-Segment exchange alignment time
Text = "APS shall be able to perform on-axis alignment in less than 120 minutes (at a single elevation angle) when all optics are within the post-segment exchange specifications."
TMT ID = 'REQ-2-APS-0016"

«satisfy»

«analyses»

«block»
APS Mission Conceptual
parts
APS Operational Blackbox: APS Conceptual{redefines aPS Operational Blackbox JPL}

	T Final : Real	Post Seg Xchg Time Limit : Second	Post Segment Exchange : Post Segment Exchange Time Constraint	Off Axis Measurement Steps : Integer	Off Axis Map Points : Integer	RB Dit : Integer	Phasing Dit : Integer
ptual.aps.co		7200.0	pass				
ptual.aps.co	1517.0			6	7	45	20

Analyze Realization Design/Specification 4

#	Name	Classifier	Operating Power : W	Standby Power : W
1	peak Power Limit Scenario Online.aPS Realization	APS Realization	0.0	0.0
2	peak Power Limit Scenario Online.aPS Realization.dome Installation	Dome Installation	0.0	0.0
3	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins	Instrument	0.0	0.0
4	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins.aps electronics rack	Controller Rack	0.0	0.0
5	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins.aps electronics rack.apt bs	Motor Ctrl	0.0	0.0
6	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins.aps electronics rack.apt bs.subMass[1]	MassRollUpPattern		
7	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins.aps electronics rack.apt bs.subPower[1]	PowerRollUpPattern		
8	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins.aps electronics rack.apt ccd	Camera Ctrl	150.0	200.0
9	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins.aps electronics rack.apt ccd.subMass[1]			
10	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins.aps electronics rack.apt ccd.subPower[1]			
11	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins.aps electronics rack.apt filter 1			
12	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins.aps electronics rack.apt filter 1.subMass[1]			
13	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins.aps electronics rack.apt filter 1.subPower[1]			
14	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins.aps electronics rack.apt filter 2			
15	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins.aps electronics rack.apt filter 3			
16	peak Power Limit Scenario Online.aPS Realization.dome Installation.ins.aps electronics rack.pit ccd	Camera Ctrl	150.0	100.0

Pass/fail

Change request 1

Max duration Post-segment exchange: ~~7200s~~ 5000s

Number of exposures of 45s 4 ~~6~~

Max peak power consumption in dome: 8.5kw ~~8.1kw~~

Number of motors with 50W 10 1~~2~~

Produce Engineering Documents 5

Systems Model is developed according to ESEM using Cookbook Patterns

- Define APS Mission boundaries
- Elaborate Conceptual Architecture
- Capture Component Behavior and Characteristics
- Specify Interactions between Components
- Run Analyses

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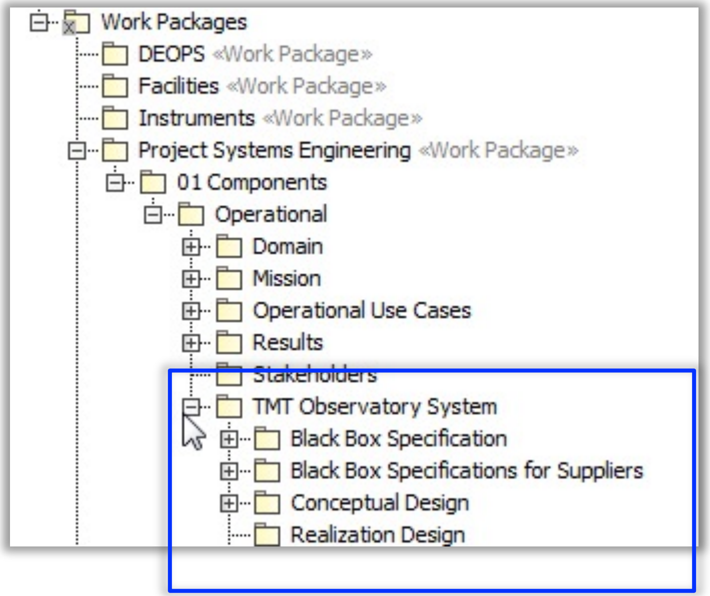
Requirements Verification

- **Intent**
  - Validate requirements, verify as designed system against requirements and publish analysis results
- **Cookbook Volume**
  - System Requirements Management
- **Educational example**
  - Autonomous Ferry Transportation
- **Known Uses**
  - APS - Post-segment exchange timing requirements
- **Tooling**
  - Cameo Systems Modeler and Simulation Toolkit, View Editor
- **Notes**
  - Property Based Requirements links Requirements Management and System Design

Package Organization

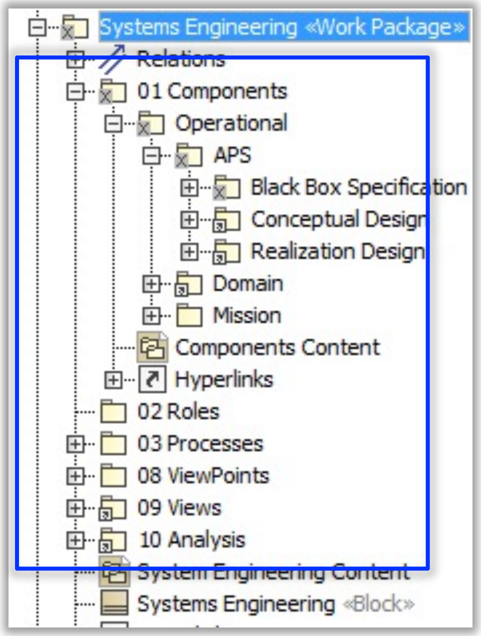
Model Organization Principles



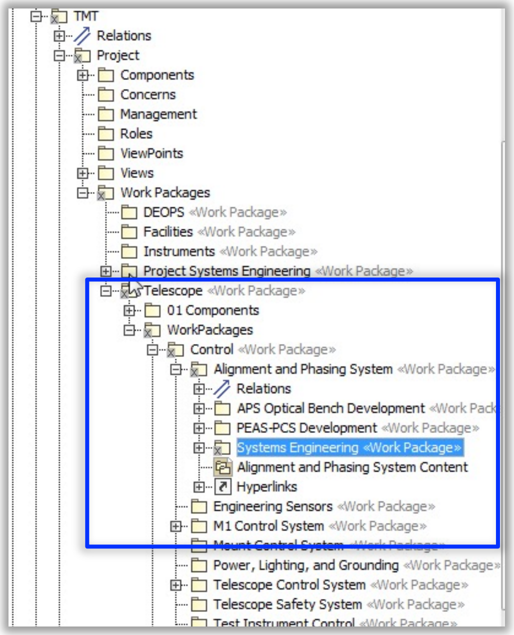
```
Work Packages
    DEOPS «Work Package»
    Facilities «Work Package»
    Instruments «Work Package»
    Project Systems Engineering «Work Package»
        01 Components
            Operational
                Domain
                Mission
                Operational Use Cases
                Results
                Stakeholders
                TMT Observatory System
                    Black Box Specification
                    Black Box Specifications for Suppliers
                    Conceptual Design
                    Realization Design
```

Customer / supplier relationship

OOSEM abstraction layers



```
Systems Engineering «Work Package»
    Relations
    01 Components
        Operational
            APS
                Black Box Specification
                Conceptual Design
                Realization Design
            Domain
            Mission
        Components Content
        Hyperlinks
    02 Roles
    03 Processes
    08 ViewPoints
    09 Views
    10 Analysis
    System Engineering Content
    Systems Engineering «Block»
```

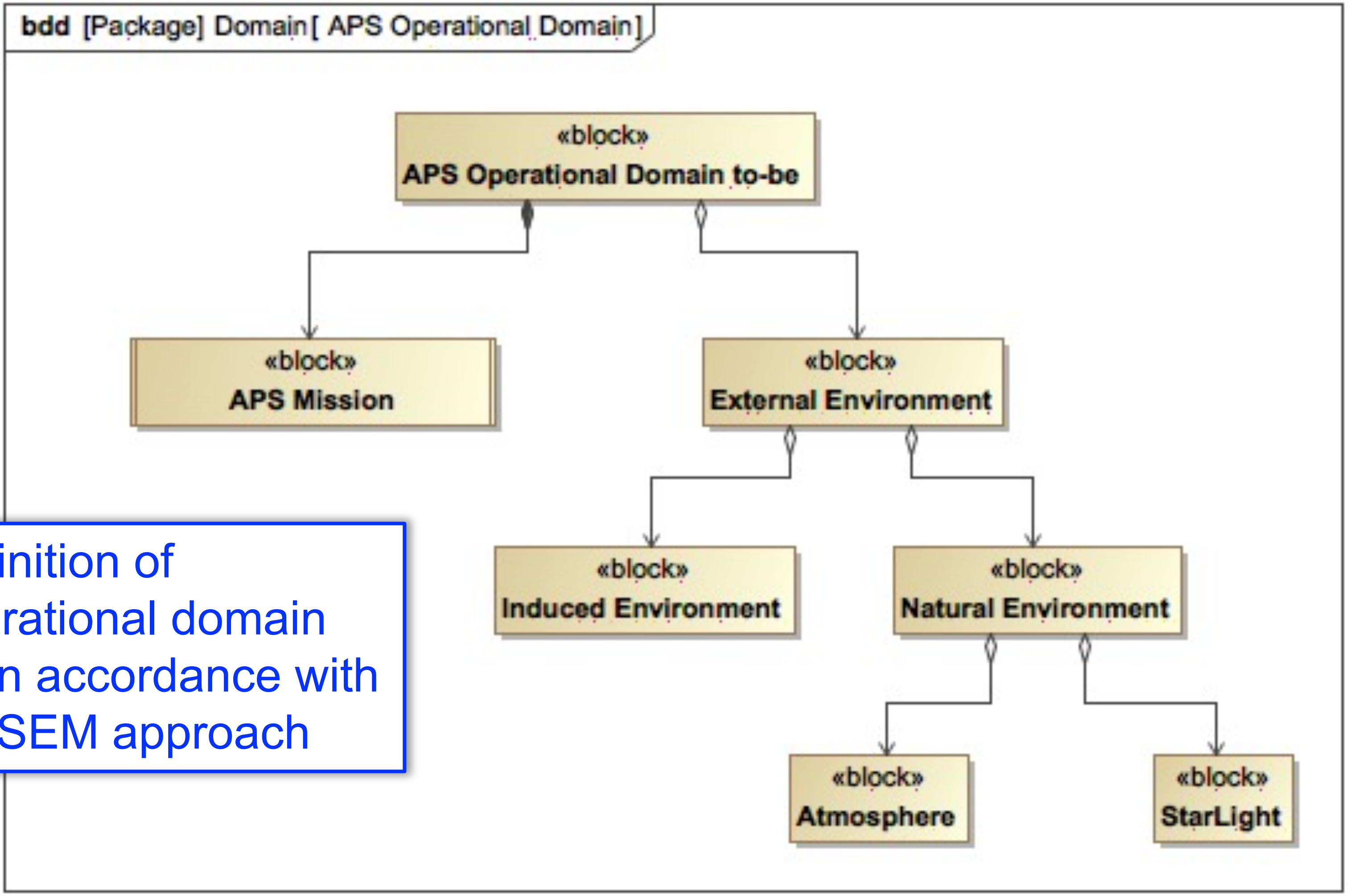


```
TMT
    Relations
    Project
        Components
        Concerns
        Management
        Roles
        ViewPoints
        Views
        Work Packages
            DEOPS «Work Package»
            Facilities «Work Package»
            Instruments «Work Package»
            Project Systems Engineering «Work Package»
            Telescope «Work Package»
                01 Components
                WorkPackages
                    Control «Work Package»
                        Alignment and Phasing System «Work Package»
                            Relations
                            APS Optical Bench Development «Work Pack
                            PEAS-PCS Development «Work Package»
                            Systems Engineering «Work Package»
                            Alignment and Phasing System Content
                            Hyperlinks
                        Engineering Sensors «Work Package»
                        M1 Control System «Work Package»
                        Mount Control System «Work Package»
                        Power, Lighting, and Grounding «Work Package»
                        Telescope Control System «Work Package»
                        Telescope Safety System «Work Package»
                        Test Instrument Control «Work Package»
```

Work breakdown structure

Operational Domain

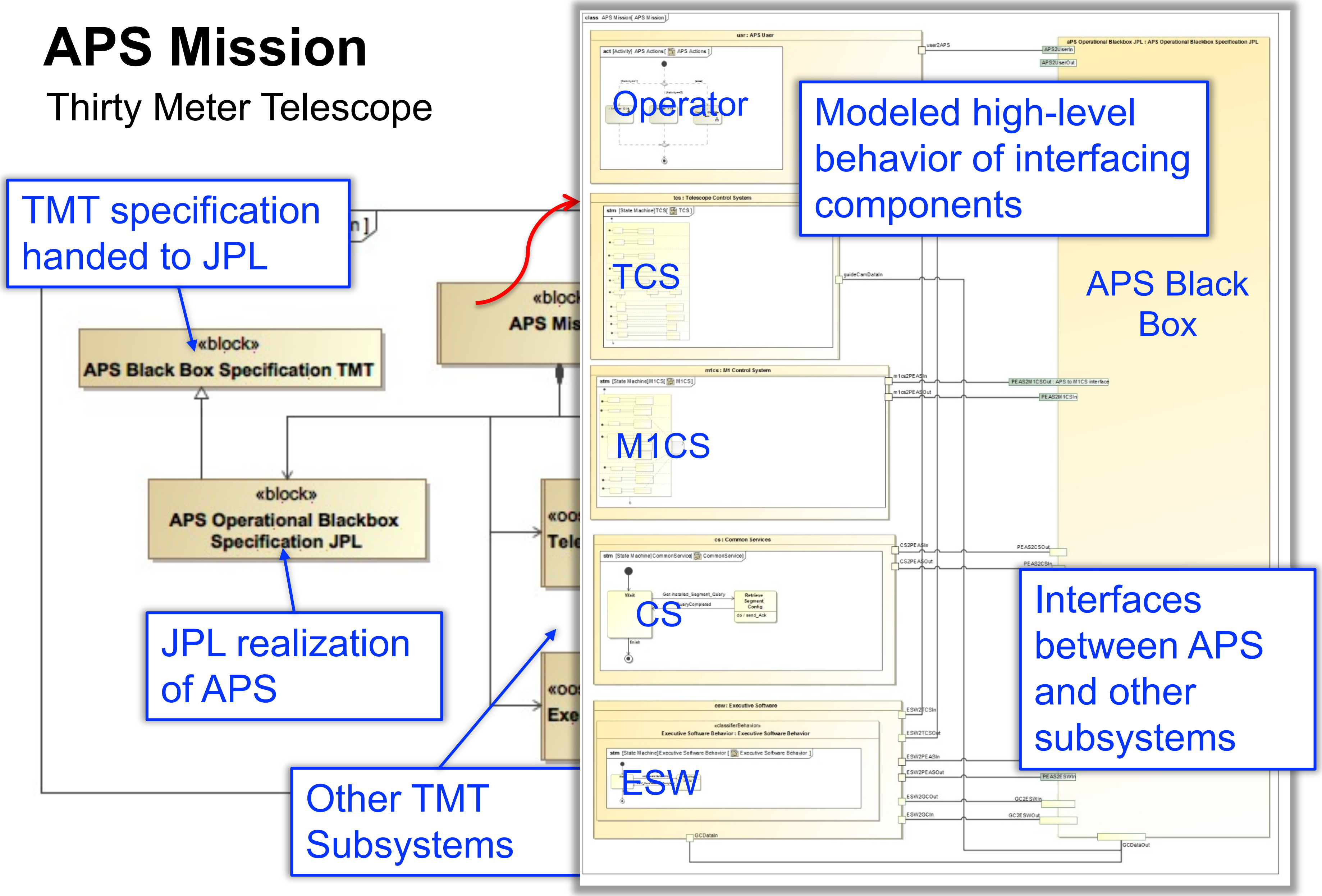
Thirty Meter Telescope



Definition of operational domain as in accordance with OOSEM approach

APS Mission

Thirty Meter Telescope



TMT specification handed to JPL

JPL realization of APS

Other TMT Subsystems

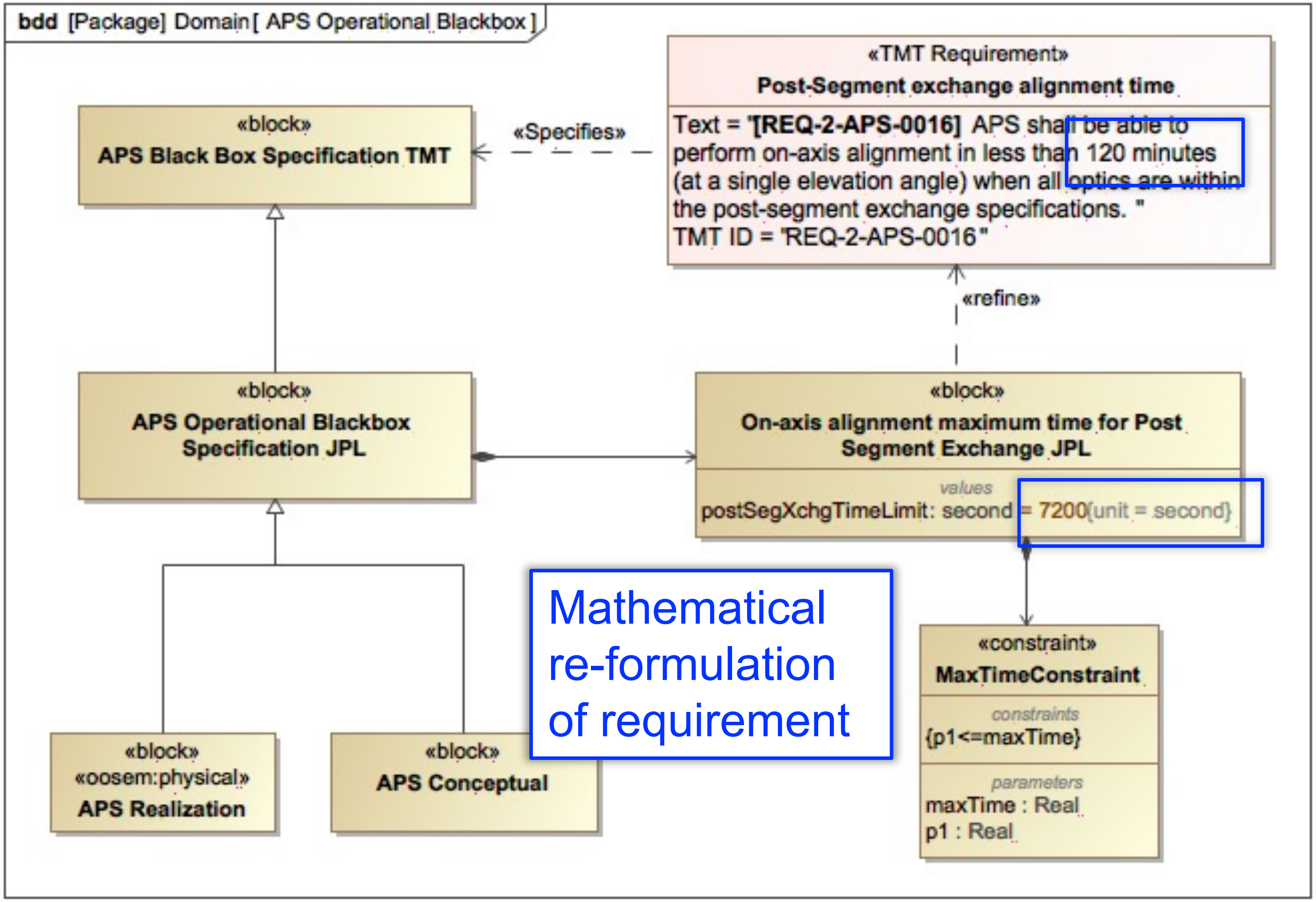
Modeled high-level behavior of interfacing components

Interfaces between APS and other subsystems

«block»
APS Black Box Specification TMT
«block»
APS Operational Blackbox Specification JPL
«block»
APS Mis
«OOS
Tele
«OOS
Exe
class APS Mission[APS Mission]
usr : APS User
act [Activity] APS Actions[APS Actions]
Operator
tcs : Telescope Control System
stm [State Machine]TCS[TCS]
TCS
m1cs : M1 Control System
stm [State Machine]M1CS[M1CS]
M1CS
cs : Common Services
stm [State Machine]CommonService[CommonService]
CS
Wait
Get installed_Segment_Query
Retrieve Segment Config
do / send_Ack
finish
esw : Executive Software
«classifierBehavior»
Executive Software Behavior : Executive Software Behavior
stm [State Machine]Executive Software Behavior [Executive Software Behavior]
ESW
aPS Operational Blackbox JPL : APS Operational Blackbox Specification JPL
APS Black Box
user2APS
APS2UserIn
APS2UserOut
guideCamDataIn
m1cs2PEASIn
m1cs2PEASOut
PEAS2M1CSOut : APS to M1CS interface
PEAS2M1CSIn
CS2PEASIn
CS2PEASOut
PEAS2CSOut
PEAS2CSIn
ESW2TCSIn
ESW2TCSOut
ESW2PEASIn
ESW2PEASOut
PEAS2ESWIn
ESW2GCOut
ESW2GCIn
GC2ESWIn
GC2ESWOut
GCDataIn
GCDataOut

Formalizing Requirements

Thirty Meter Telescope



bdd [Package] Domain[APS Operational Blackbox]

«TMT Requirement»
Post-Segment exchange alignment time

Text = "**[REQ-2-APS-0016]** APS shall be able to perform on-axis alignment in less than 120 minutes (at a single elevation angle) when all optics are within the post-segment exchange specifications. "
TMT ID = "REQ-2-APS-0016"

«block»
APS Black Box Specification TMT

«Specifies»

«refine»

«block»
APS Operational Blackbox Specification JPL

«block»
On-axis alignment maximum time for Post Segment Exchange JPL

values
postSegXchgTimeLimit : second = 7200{unit = second}

«constraint»
MaxTimeConstraint

constraints
{p1<=maxTime}

parameters
maxTime : Real
p1 : Real

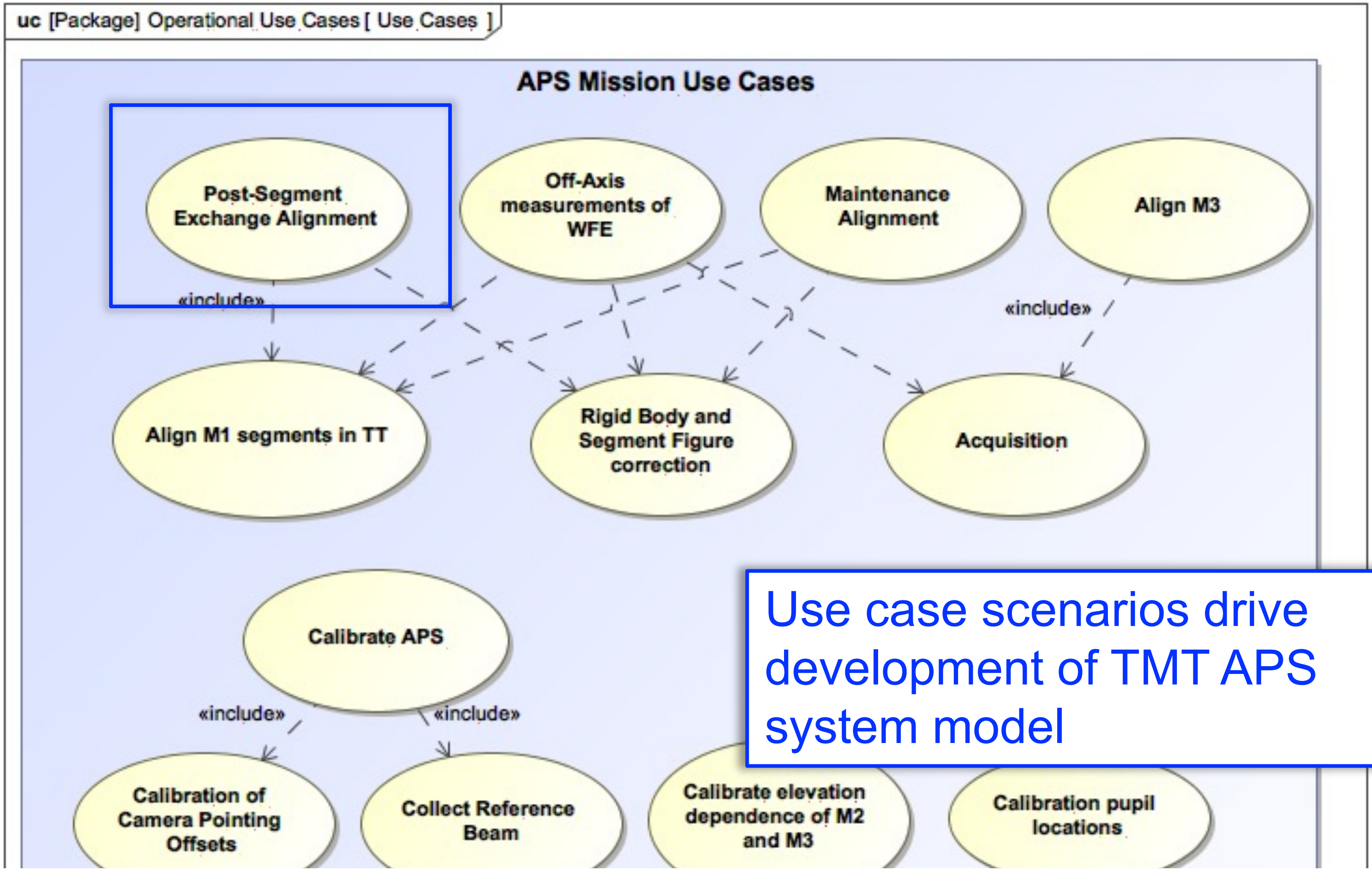
«block»
«oosem:physical»
APS Realization

«block»
APS Conceptual

Mathematical re-formulation of requirement

Use Cases

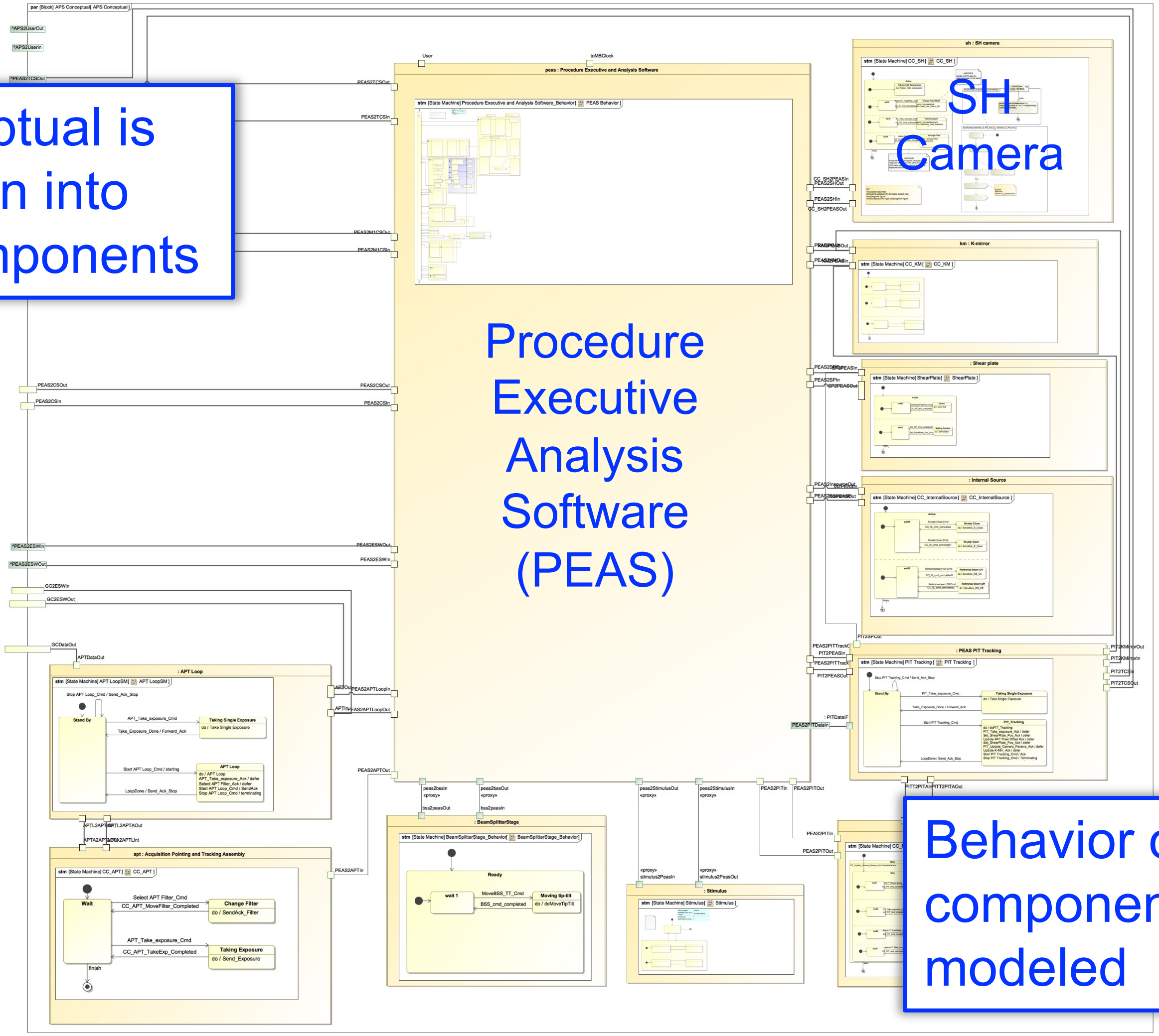
Thirty Meter Telescope


uc [Package] Operational Use Cases [Use Cases]
APS Mission Use Cases
Post-Segment Exchange Alignment
Off-Axis measurements of WFE
Maintenance Alignment
Align M3
«include»
«include»
Align M1 segments in TT
Rigid Body and Segment Figure correction
Acquisition
Calibrate APS
«include»
«include»
Calibration of Camera Pointing Offsets
Collect Reference Beam
Calibrate elevation dependence of M2 and M3
Calibration pupil locations

Use case scenarios drive development of TMT APS system model

Conceptual Architecture

Thirty Meter Telescope

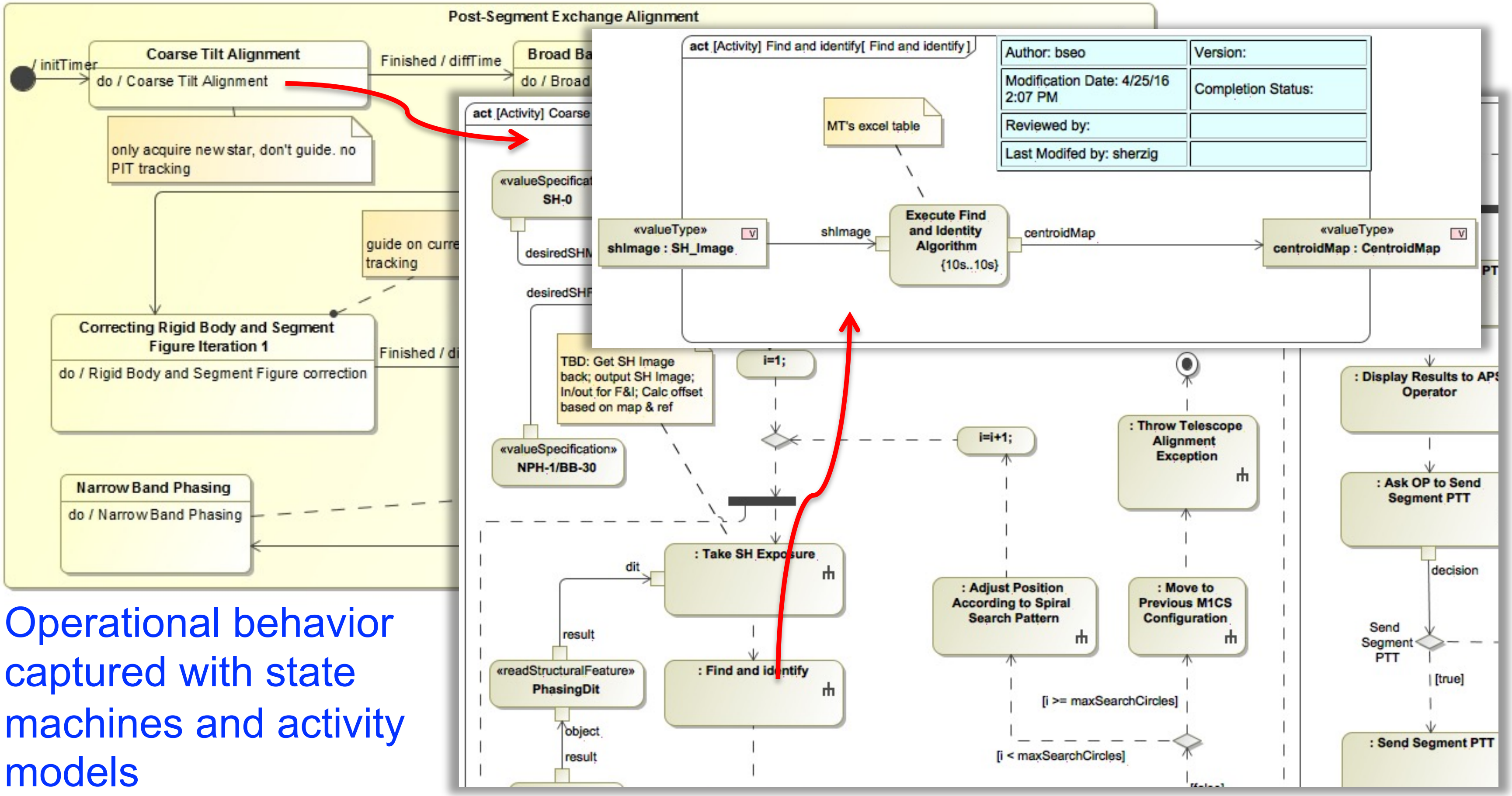

par [Block] APS Conceptual[APS Conceptual]
peas : Procedure Executive and Analysis Software
sh : SH camera
km : K-mirror
: Shear plate
: Internal Source
: PEAS PIT Tracking
: APT Loop
apt : Acquisition Pointing and Tracking Assembly
: BeamSplitterStage
: Stimulus
Procedure Executive Analysis Software (PEAS)
SH Camera

APS conceptual is broken down into several components

Behavior of all components modeled

Modeling Behavior

Thirty Meter Telescope

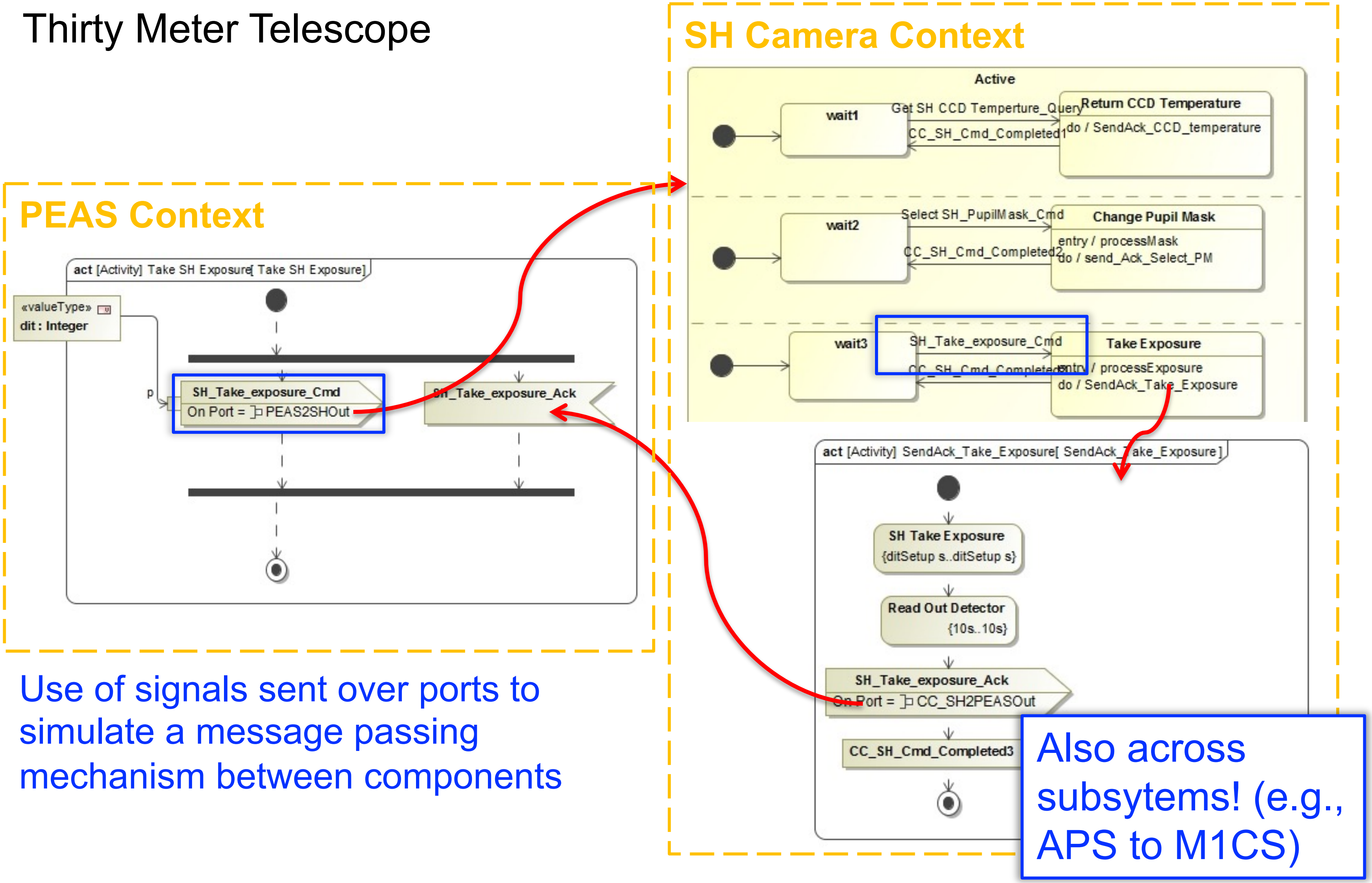

Post-Segment Exchange Alignment
/ initTimer
Coarse Tilt Alignment
do / Coarse Tilt Alignment
Finished / diffTime
Broad Ba
do / Broad
only acquire new star, don't guide. no PIT tracking
guide on curre tracking
Correcting Rigid Body and Segment Figure Iteration 1
do / Rigid Body and Segment Figure correction
Finished / di
Narrow Band Phasing
do / Narrow Band Phasing
act [Activity] Coarse
«valueSpecificat SH-0
desiredSHM
desiredSHF
TBD: Get SH Image back; output SH Image; In/out for F&I; Calc offset based on map & ref
«valueSpecification» NPH-1/BB-30
i=1;
i=i+1;
: Throw Telescope Alignment Exception
: Display Results to APS Operator
: Ask OP to Send Segment PTT
decision
Send Segment PTT
[true]
: Send Segment PTT
dit
: Take SH Exposure
result
«readStructuralFeature» PhasingDit
object
result
: Find and identify
: Adjust Position According to Spiral Search Pattern
: Move to Previous M1CS Configuration
[i >= maxSearchCircles]
[i < maxSearchCircles]
[false]
act [Activity] Find and identify[Find and identify]
MT's excel table
«valueType» shImage : SH_Image
shImage
Execute Find and Identity Algorithm {10s..10s}
centroidMap
«valueType» centroidMap : CentroidMap
PT

Author: bseo	Version:
Modification Date: 4/25/16 2:07 PM	Completion Status:
Reviewed by:	
Last Modifed by: sherzig	

Operational behavior captured with state machines and activity models

Interactions Between Components

Thirty Meter Telescope

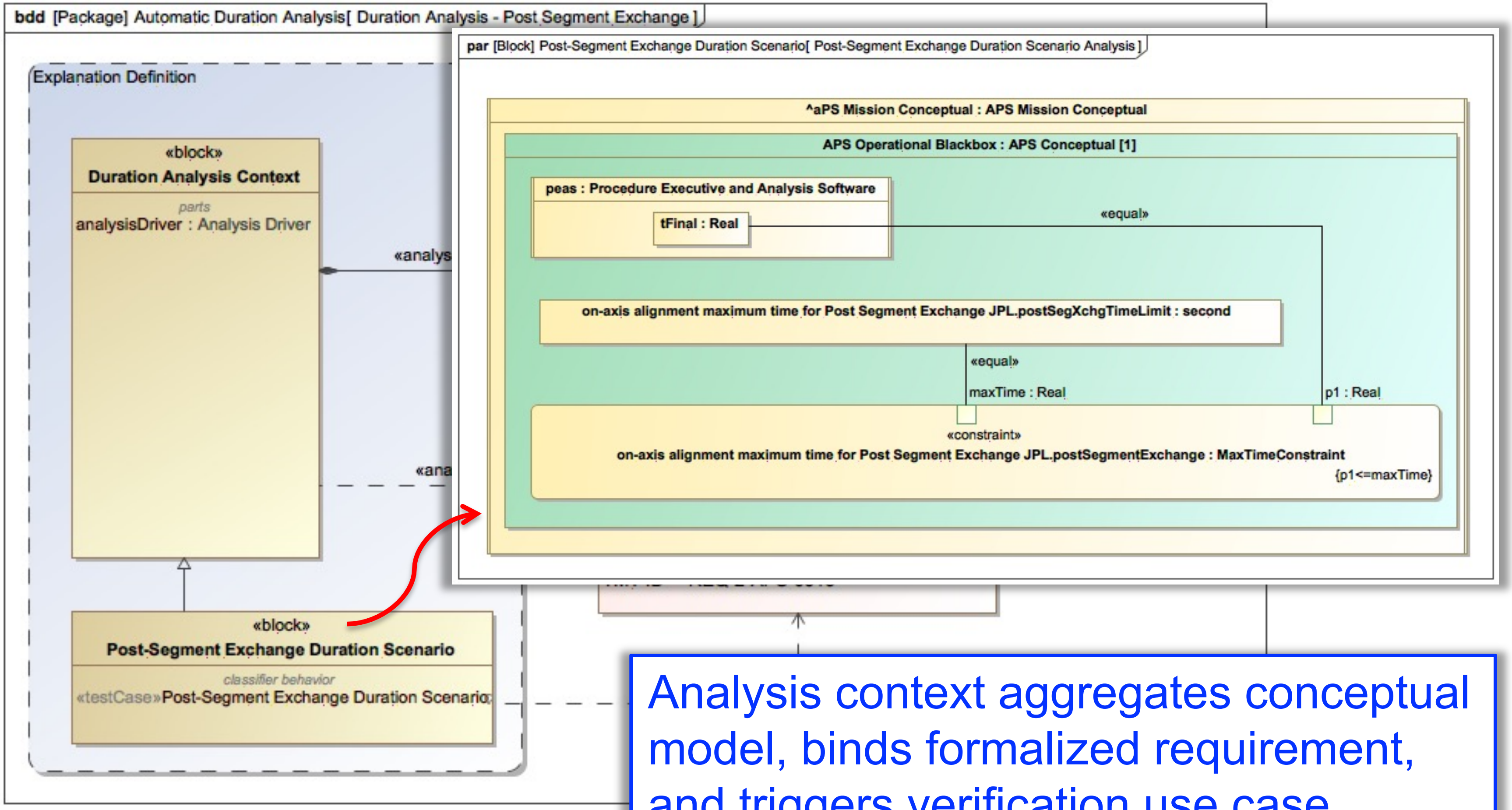


Use of signals sent over ports to simulate a message passing mechanism between components

Also across subsytems! (e.g., APS to M1CS)

Verifying Timing Requirements by Simulation

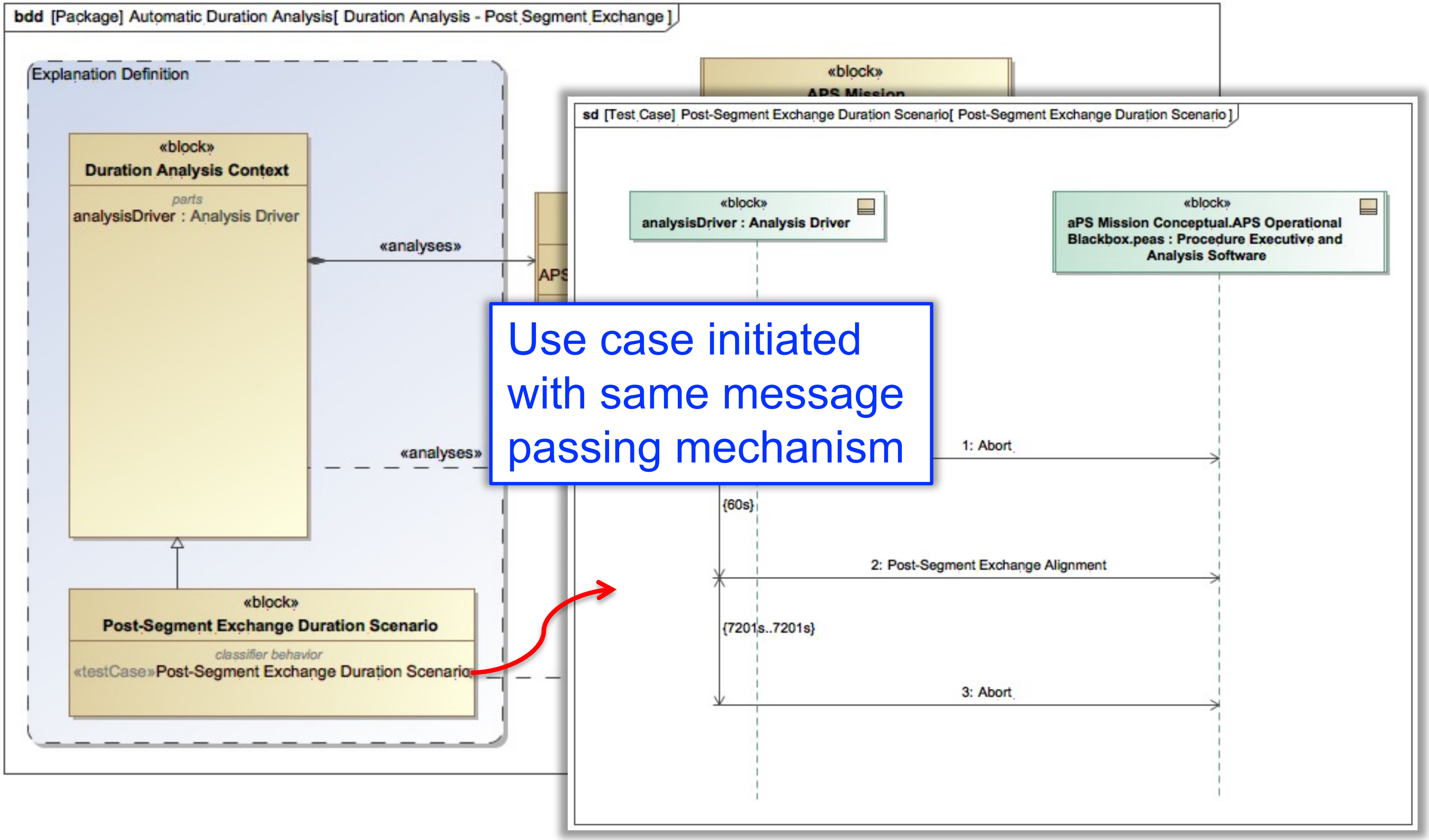
Thirty Meter Telescope


bdd [Package] Automatic Duration Analysis[Duration Analysis - Post Segment Exchange]
Explanation Definition
«block»
Duration Analysis Context
parts
analysisDriver : Analysis Driver
«analys
«ana
«block»
Post-Segment Exchange Duration Scenario
classifier behavior
«testCase»Post-Segment Exchange Duration Scenario
par [Block] Post-Segment Exchange Duration Scenario[Post-Segment Exchange Duration Scenario Analysis]
^aPS Mission Conceptual : APS Mission Conceptual
APS Operational Blackbox : APS Conceptual [1]
peas : Procedure Executive and Analysis Software
tFinal : Real
«equal»
on-axis alignment maximum time for Post Segment Exchange JPL.postSegXchgTimeLimit : second
«equal»
maxTime : Real
p1 : Real
«constraint»
on-axis alignment maximum time for Post Segment Exchange JPL.postSegmentExchange : MaxTimeConstraint
{p1<=maxTime}

Analysis context aggregates conceptual model, binds formalized requirement, and triggers verification use case

Verifying Timing Requirements by Simulation

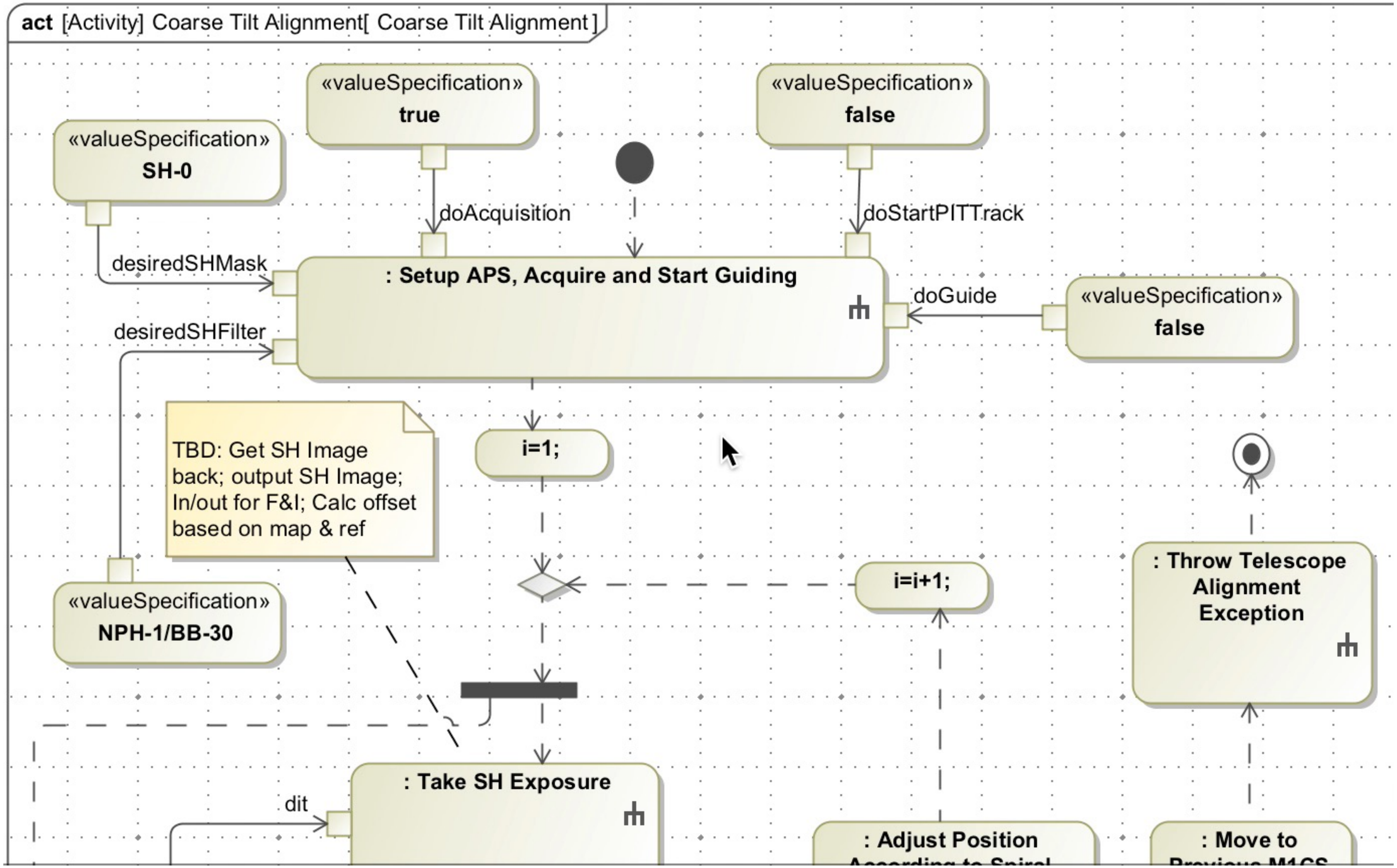
Thirty Meter Telescope


bdd [Package] Automatic Duration Analysis[Duration Analysis - Post Segment Exchange]
Explanation Definition
«block»
Duration Analysis Context
parts
analysisDriver : Analysis Driver
«analyses»
APS
«analyses»
«block»
APS Mission
«block»
Post-Segment Exchange Duration Scenario
classifier behavior
«testCase»Post-Segment Exchange Duration Scenario
sd [Test Case] Post-Segment Exchange Duration Scenario[Post-Segment Exchange Duration Scenario]
«block»
analysisDriver : Analysis Driver
«block»
aPS Mission Conceptual.APS Operational Blackbox.peas : Procedure Executive and Analysis Software
1: Abort
{60s}
2: Post-Segment Exchange Alignment
{7201s..7201s}
3: Abort

Use case initiated with same message passing mechanism

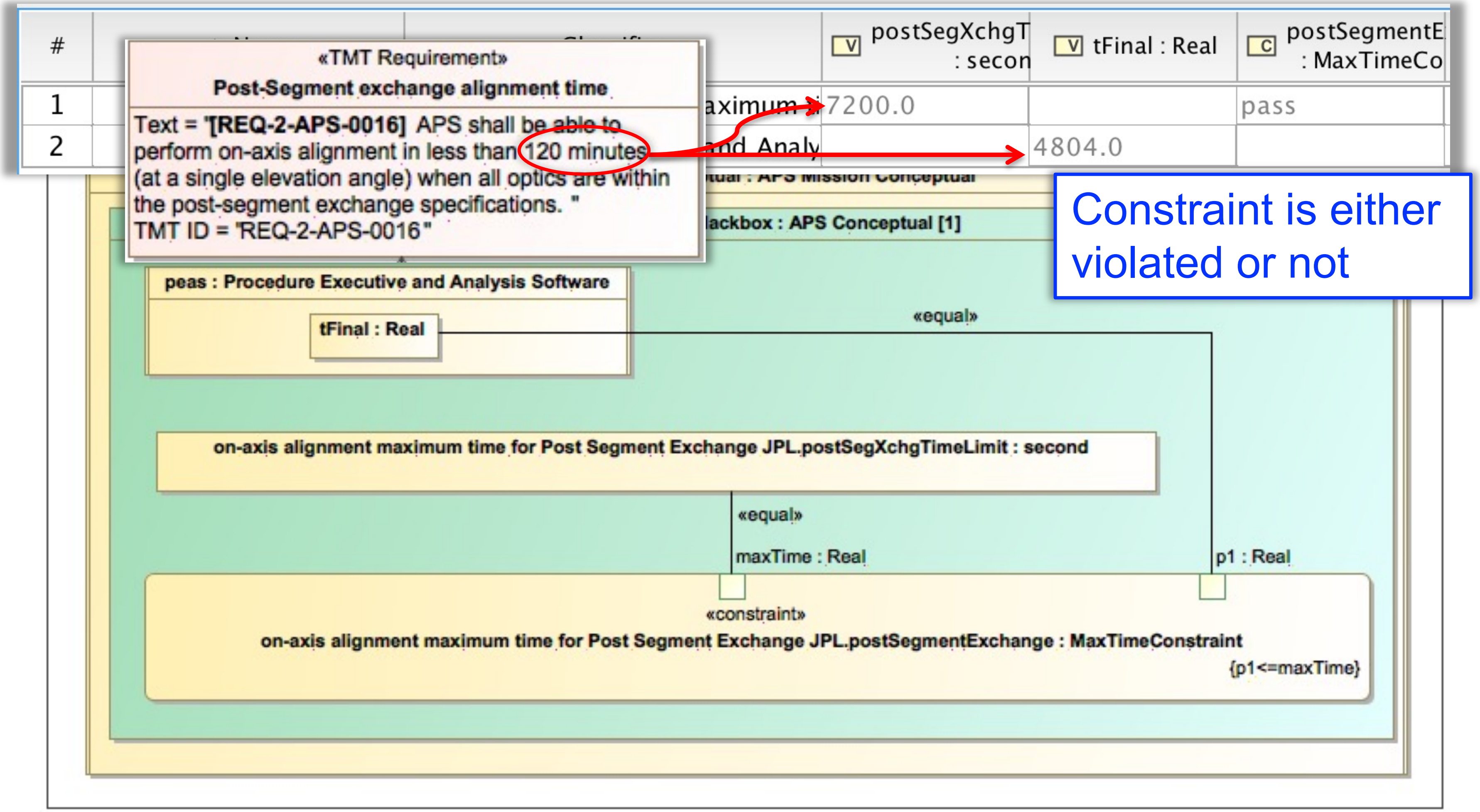
Verifying Timing Requirements by Simulation

Thirty Meter Telescope


act [Activity] Coarse Tilt Alignment[Coarse Tilt Alignment]
«valueSpecification»
SH-0
«valueSpecification»
true
«valueSpecification»
false
doAcquisition
doStartPITTrack
desiredSHMask
desiredSHFilter
: Setup APS, Acquire and Start Guiding
doGuide
«valueSpecification»
false
TBD: Get SH Image back; output SH Image; In/out for F&I; Calc offset based on map & ref
i=1;
i=i+1;
: Throw Telescope Alignment Exception
«valueSpecification»
NPH-1/BB-30
dit
: Take SH Exposure
: Adjust Position According to Spiral
: Move to Previous M1CS

Verifying Timing Requirements by Simulation

Thirty Meter Telescope



#			V postSegXchgT : secon	V tFinal : Real	C postSegmentE : MaxTimeCo
1		aximum	7200.0		pass
2		nd Analy		4804.0	

«TMT Requirement»
Post-Segment exchange alignment time

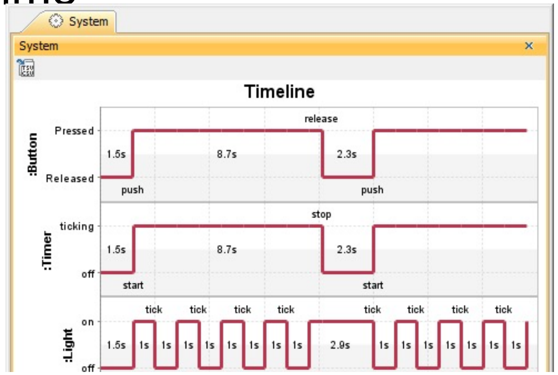
Text = "[REQ-2-APS-0016] APS shall be able to perform on-axis alignment in less than 120 minutes (at a single elevation angle) when all optics are within the post-segment exchange specifications. "
TMT ID = "REQ-2-APS-0016"

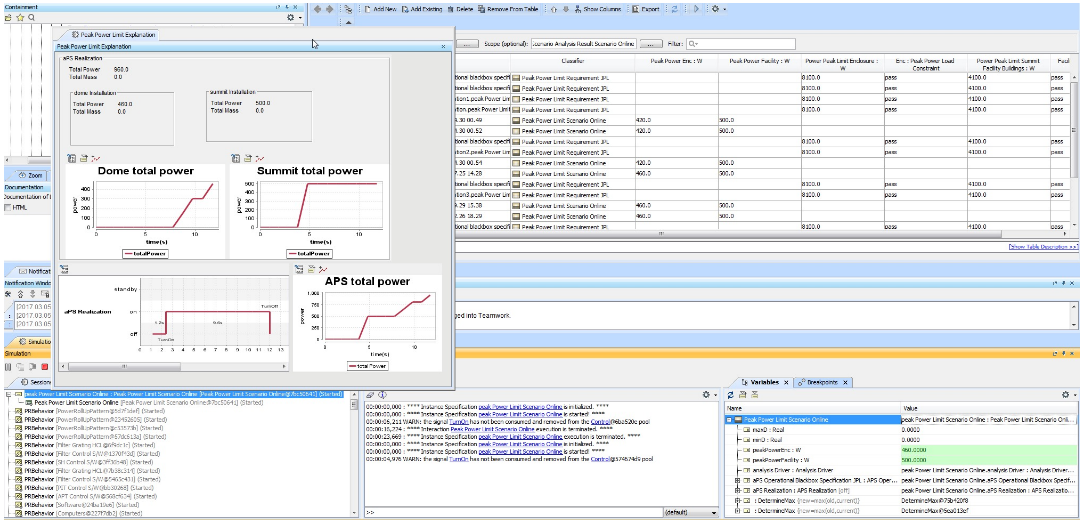
tual : APS Mission Conceptual
lackbox : APS Conceptual [1]
peas : Procedure Executive and Analysis Software
tFinal : Real
«equal»
on-axis alignment maximum time for Post Segment Exchange JPL.postSegXchgTimeLimit : second
«equal»
maxTime : Real
p1 : Real
«constraint»
on-axis alignment maximum time for Post Segment Exchange JPL.postSegmentExchange : MaxTimeConstraint
{p1<=maxTime}

Constraint is either violated or not

Run Analyses

- Run a configured analysis with a simulation engine on the initial conditions to get the final conditions
- Produce the analyses declaratively, repeatably (in any system), without a single line of project-specific code -> reducing time and resources
- Produce the following views on final conditions
  - **Table** showing final analysis values (e.g. peak power) and the constraint's pass/fail status for each scenario
  - **Timelines**: state changes for components over time
  - **Value profiles**: total rolled up values over time





Peak Power Limit Explanation

aPS Realization
Total Power 960.0
Total Mass 0.0

dome Installation
Total Power 460.0
Total Mass 0.0

summit Installation
Total Power 500.0
Total Mass 0.0

Scope (optional): Scenario Analysis Result Scenario Online

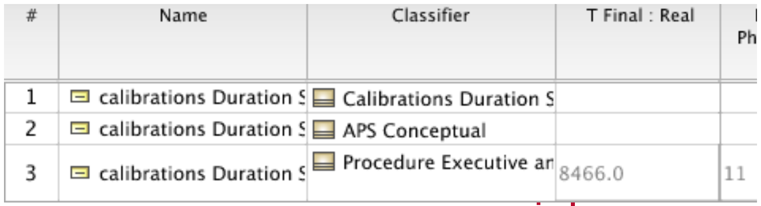
	Classifier	Peak Power Enc : W	Peak Power Facility : W	Power Peak Limit Enclosure : W	Enc : Peak Power Load Constraint	Power Peak Limit Summit Facility Buildings : W	Facil
tional blackbox specifi	Peak Power Limit Requirement JPL			8100.0	pass	4100.0	pass
tional blackbox specifi	Peak Power Limit Requirement JPL			8100.0	pass	4100.0	pass
tion1.peak Power Lim	Peak Power Limit Requirement JPL			8100.0	pass	4100.0	pass
tion.peak Power Limit	Peak Power Limit Requirement JPL			8100.0	pass	4100.0	pass
.30 00.49	Peak Power Limit Scenario Online	420.0	500.0				
.30 00.52	Peak Power Limit Scenario Online	420.0	500.0				
tional blackbox specifi	Peak Power Limit Requirement JPL			8100.0	pass	4100.0	pass
tion2.peak Power Lim	Peak Power Limit Requirement JPL			8100.0	pass	4100.0	pass
.30 00.54	Peak Power Limit Scenario Online	420.0	500.0				
7.25 14.28	Peak Power Limit Scenario Online	460.0	500.0				
tional blackbox specifi	Peak Power Limit Requirement JPL			8100.0	pass	4100.0	pass
tion3.peak Power Lim	Peak Power Limit Requirement JPL			8100.0	pass	4100.0	pass
.29 15.38	Peak Power Limit Scenario Online	460.0	500.0				
2.26 18.29	Peak Power Limit Scenario Online	460.0	500.0				
tional blackbox specifi	Peak Power Limit Requirement JPL			8100.0	pass	4100.0	pass

[Show Table Description >>]

```
peak Power Limit Scenario Online : Peak Power Limit Scenario Online [Peak Power Limit Scenario Online@7bc50641] (Started)
  Peak Power Limit Scenario Online [Peak Power Limit Scenario Online@7bc50641] (Started)
PRBehavior [PowerRollUpPattern@5d7f1def] (Started)
PRBehavior [PowerRollUpPattern@23452605] (Started)
PRBehavior [PowerRollUpPattern@c53573b] (Started)
PRBehavior [PowerRollUpPattern@57dc613a] (Started)
PRBehavior [Filter Grating HCL@6f9dc1c] (Started)
PRBehavior [Filter Control S/W@1370f43d] (Started)
PRBehavior [SH Control S/W@3ff36b48] (Started)
PRBehavior [Filter Grating HCL@7b38c314] (Started)
PRBehavior [Filter Control S/W@5465c431] (Started)
PRBehavior [PIT Control S/W@bb30268] (Started)
PRBehavior [APT Control S/W@568cf634] (Started)
PRBehavior [Software@24ba19e6] (Started)
PRBehavior [Computers@227f7db2] (Started)
```

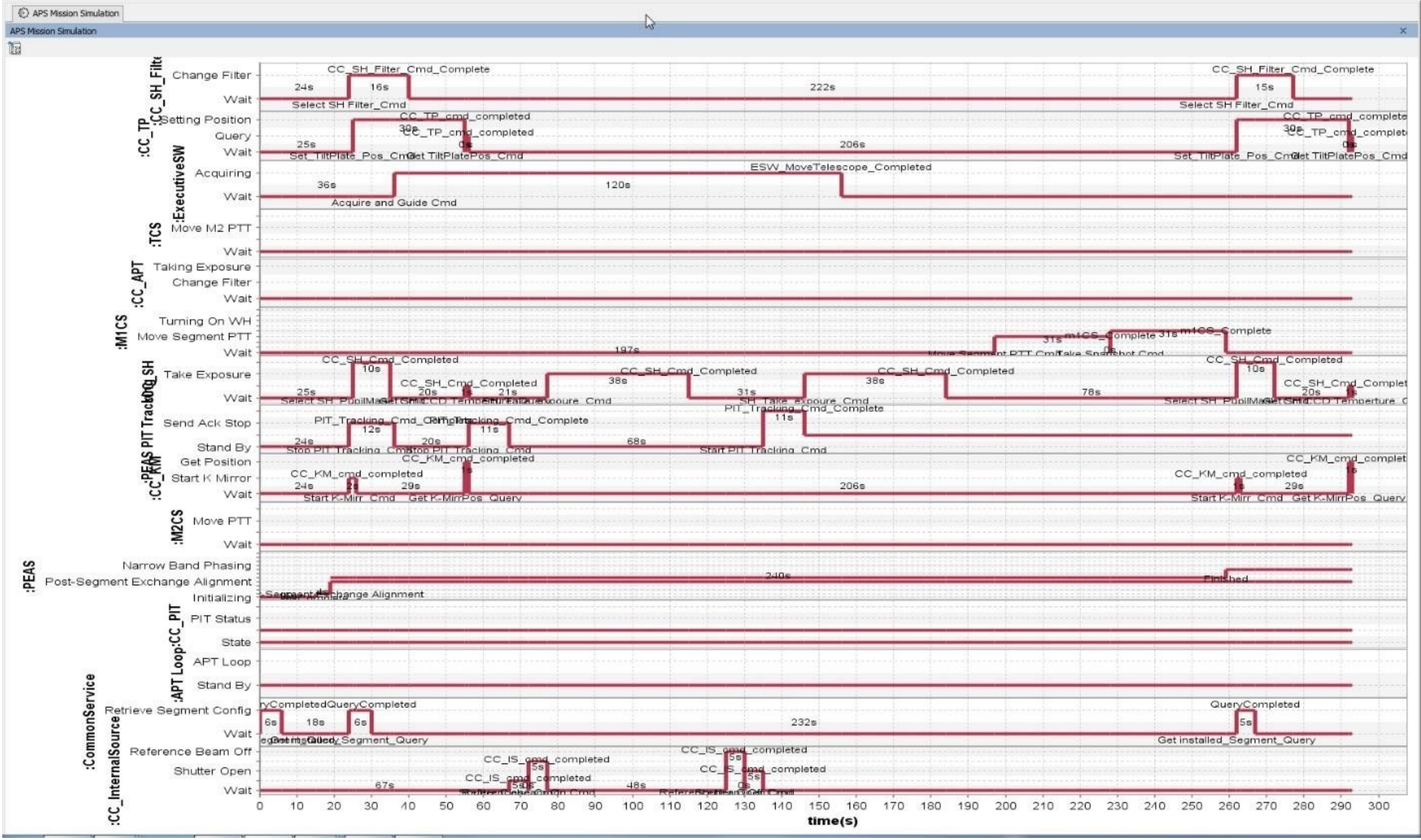
```
00:00:00,000 : **** Instance Specification peak Power Limit Scenario Online is initialized. ****
00:00:00,000 : **** Instance Specification peak Power Limit Scenario Online is started! ****
00:00:06,211 WARN: the signal TurnOn has not been consumed and removed from the Control@6ba520e pool
00:00:16,224 : **** Interaction Peak Power Limit Scenario Online execution is terminated. ****
00:00:23,669 : **** Instance Specification peak Power Limit Scenario Online execution is terminated. ****
00:00:00,000 : **** Instance Specification peak Power Limit Scenario Online is initialized. ****
00:00:00,000 : **** Instance Specification peak Power Limit Scenario Online is started! ****
00:00:04,976 WARN: the signal TurnOn has not been consumed and removed from the Control@574674d9 pool
>>
```

Name	Value
Peak Power Limit Scenario Online	peak Power Limit Scenario Online : Peak Power Limit Scenario Onli...
maxD : Real	0.0000
minD : Real	0.0000
peakPowerEnc : W	460.0000
peakPowerFacility : W	500.0000
analysis Driver : Analysis Driver	peak Power Limit Scenario Online.analysis Driver : Analysis Driver...
aPS Operational Blackbox Specification JPL : APS Oper...	peak Power Limit Scenario Online.aPS Operational Blackbox Specif...
aPS Realization : APS Realization [off]	peak Power Limit Scenario Online.aPS Realization : APS Realizatio...
: DetermineMax {new=max(old,current)}	DetermineMax@75b420f8
: DetermineMax {new=max(old,current)}	DetermineMax@5ea013ef

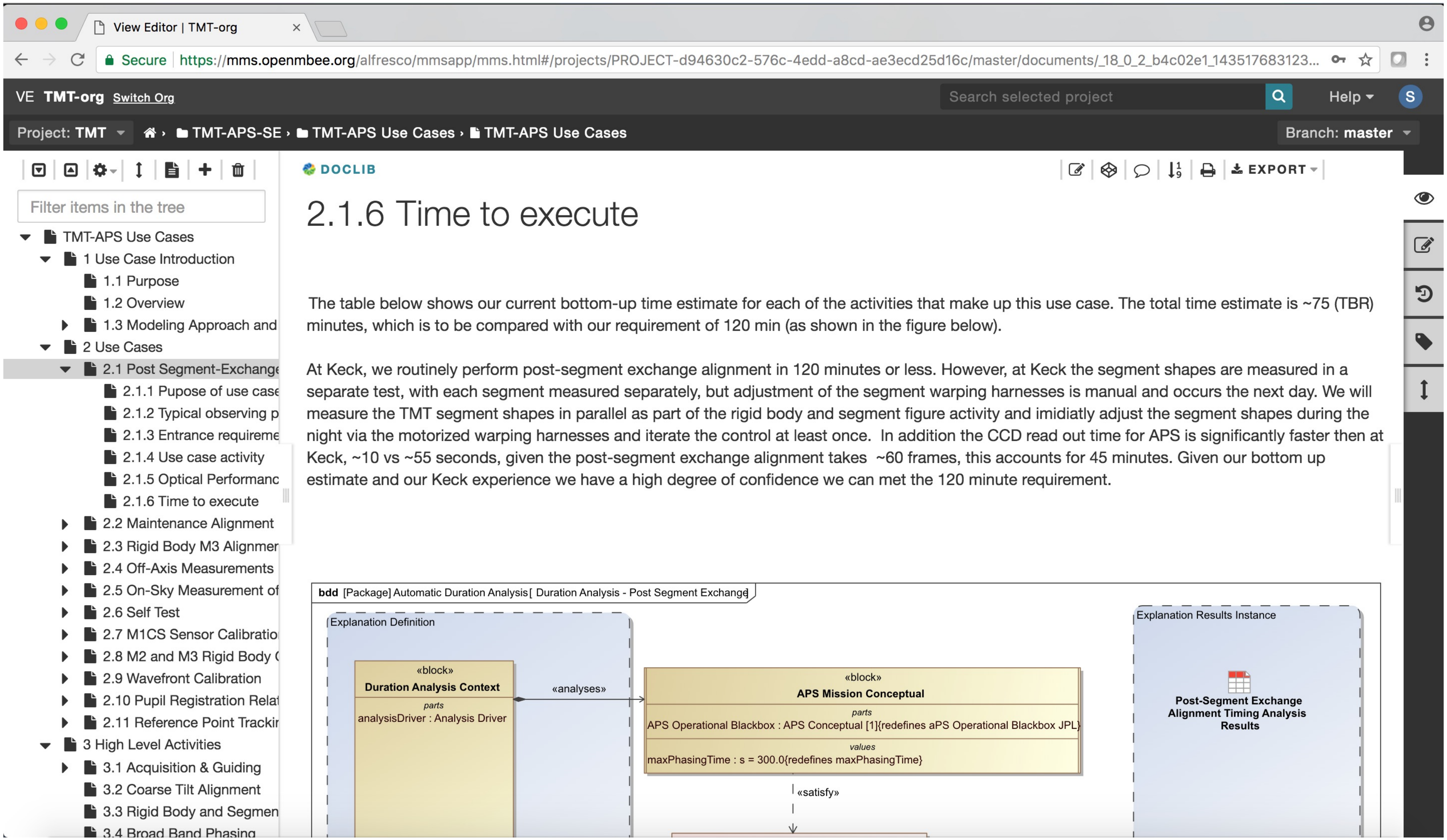


#	Name	Classifier	T Final : Real	Ph
1	calibrations Duration S	Calibrations Duration S		
2	calibrations Duration S	APS Conceptual		
3	calibrations Duration S	Procedure Executive ar	8466.0	11

Timeline of component states



Document & Report Generation via View Editor


View Editor | TMT-org
Secure https://mms.openmbee.org/alfresco/mmsapp/mms.html#/projects/PROJECT-d94630c2-576c-4edd-a8cd-ae3ecd25d16c/master/documents/_18_0_2_b4c02e1_143517683123...
VE TMT-org Switch Org
Search selected project
Help
Project: TMT
TMT-APS-SE › TMT-APS Use Cases › TMT-APS Use Cases
Branch: master
Filter items in the tree
TMT-APS Use Cases
1 Use Case Introduction
1.1 Purpose
1.2 Overview
1.3 Modeling Approach and
2 Use Cases
2.1 Post Segment-Exchange
2.1.1 Pupose of use case
2.1.2 Typical observing p
2.1.3 Entrance requireme
2.1.4 Use case activity
2.1.5 Optical Performanc
2.1.6 Time to execute
2.2 Maintenance Alignment
2.3 Rigid Body M3 Alignmer
2.4 Off-Axis Measurements
2.5 On-Sky Measurement of
2.6 Self Test
2.7 M1CS Sensor Calibratio
2.8 M2 and M3 Rigid Body (
2.9 Wavefront Calibration
2.10 Pupil Registration Relat
2.11 Reference Point Trackir
3 High Level Activities
3.1 Acquisition & Guiding
3.2 Coarse Tilt Alignment
3.3 Rigid Body and Segmen
3.4 Broad Band Phasing
DOCLIB
EXPORT

2.1.6 Time to execute

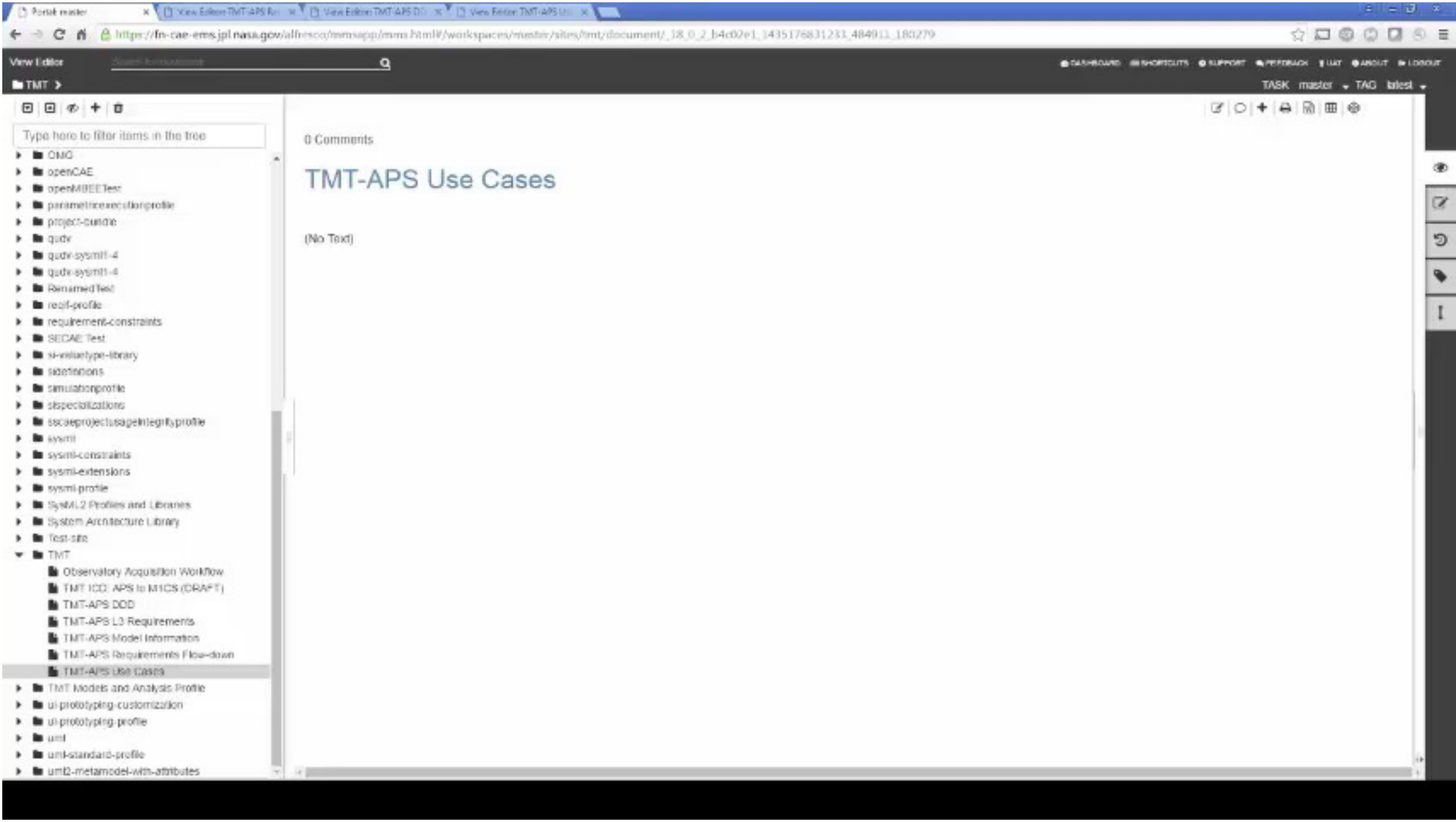
The table below shows our current bottom-up time estimate for each of the activities that make up this use case. The total time estimate is ~75 (TBR) minutes, which is to be compared with our requirement of 120 min (as shown in the figure below).

At Keck, we routinely perform post-segment exchange alignment in 120 minutes or less. However, at Keck the segment shapes are measured in a separate test, with each segment measured separately, but adjustment of the segment warping harnesses is manual and occurs the next day. We will measure the TMT segment shapes in parallel as part of the rigid body and segment figure activity and imidiatly adjust the segment shapes during the night via the motorized warping harnesses and iterate the control at least once. In addition the CCD read out time for APS is significantly faster then at Keck, ~10 vs ~55 seconds, given the post-segment exchange alignment takes ~60 frames, this accounts for 45 minutes. Given our bottom up estimate and our Keck experience we have a high degree of confidence we can met the 120 minute requirement.

bdd [Package] Automatic Duration Analysis[Duration Analysis - Post Segment Exchange]
Explanation Definition
«block»
Duration Analysis Context
parts
analysisDriver : Analysis Driver
«analyses»
«block»
APS Mission Conceptual
parts
APS Operational Blackbox : APS Conceptual [1]{redefines aPS Operational Blackbox JPL}
values
maxPhasingTime : s = 300.0{redefines maxPhasingTime}
«satisfy»
Explanation Results Instance
Post-Segment Exchange Alignment Timing Analysis Results

* OpenMBEE / ViewEditor is open source, and available at https://www.openmbee.org

System Level Analysis



0 Comments

TMT-APS Use Cases

(No Text)

Outline

- Introduction
- Thirty Meter Telescope Project (TMT) and MBSE
- OpenSE Cookbook
- TMT Requirements Verification
- ➡ JPL Systems Environment
- Summary & Conclusions

JPL Computer Aided Engineering (CAE)

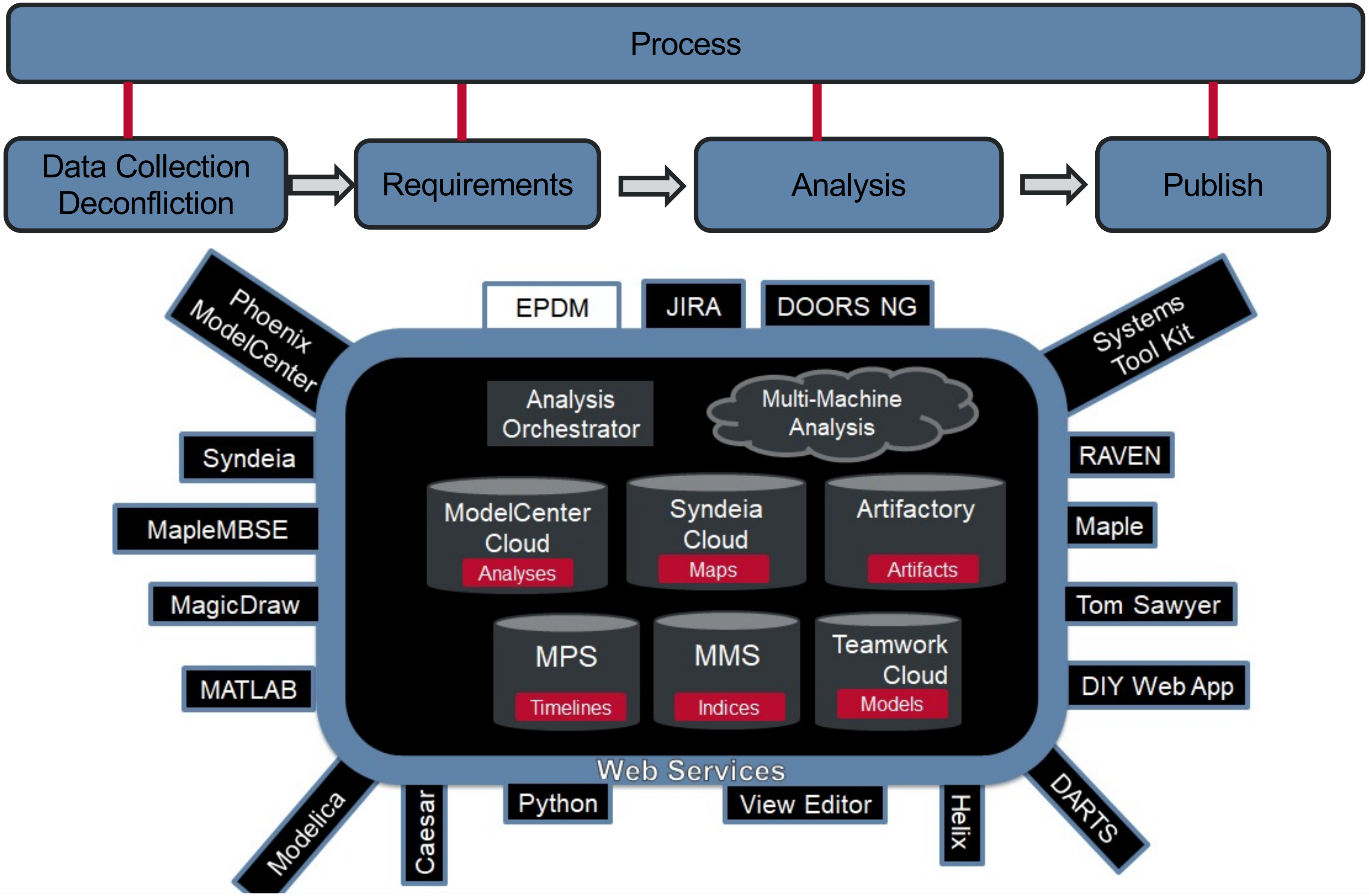
- JPL Computer Aided Engineering provides the Laboratory's Engineering Staff and Scientific communities with tools and technical expertise
- Four Environments:
  - Systems Environment
  - Software Environment
  - Mechanical Environment
  - Electrical Environment

OpenCAE provides the engineering platform

- A platform for engineering tools to work together
- Incorporate tooling from systems, software, mechanical, and electrical domains
- Platform integrates heterogenous data sources
- Emphasize standards for data interchange
- Case studies inform the architecture of the engineering environments
- Multi-model environment

For Planning and Discussion Purposes Only

JPL CAE Systems Environment provides integrated Life-Cycle Support



OpenCAE DevOps

JPL develops requirements for Systems Environment (tooling) through Case Studies

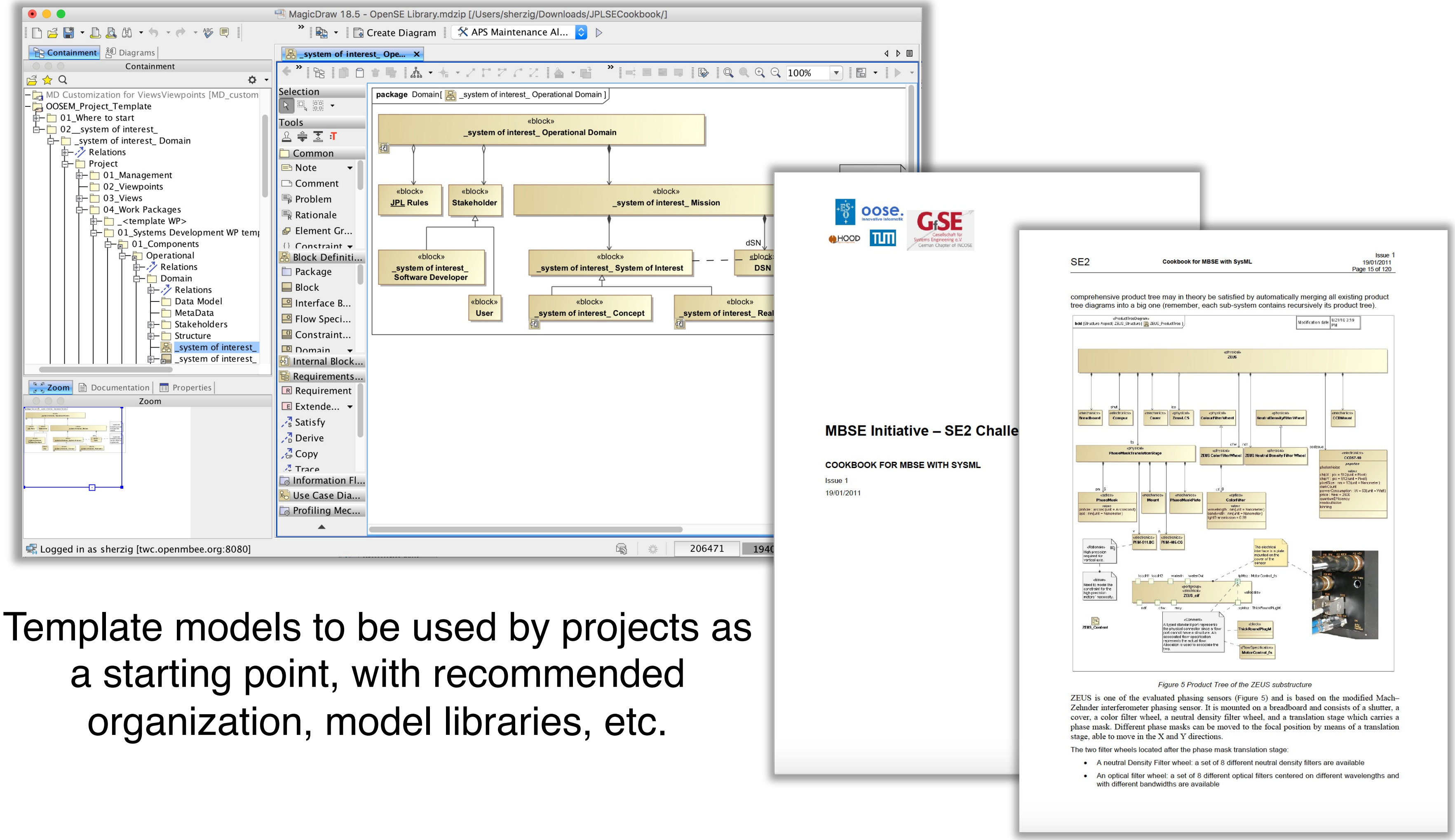
For Example:

- Requirements Management
- Interface Management
- Design Management
- Trade Studies
- Interdisciplinary Integration
- Analysis Pipeline
- Resource Management
- Timeline Management

OpenSE Cookbook combines different aspects

- Update 2012 “Cookbook for MBSE with SysML”
  - Focus on structure and requirements using European FP7 Active Phasing Experiment (APE) as case study
- Include Patterns developed for TMT
  - Focus on behavior and analysis workflows
- Guided by ESEM methodology
- Describe tooling support provided by JPL Systems Environment
- OpenSE model library provides commonly used elements
- Instructional examples
- Application to actual engineering team, i.e. TMT
- Template Models and recommended model organizations

OpenSE Cookbook and Template Model


MagicDraw 18.5 - OpenSE Library.mdzip [/Users/sherzig/Downloads/JPLSECookbook/]
Create Diagram
APS Maintenance Al...
Containment
Diagrams
MD Customization for ViewsViewpoints [MD_custom
OOSEM_Project_Template
01_Where to start
02__system of interest_
system of interest Domain
Relations
Project
01_Management
02_Viewpoints
03_Views
04_Work Packages
_<template WP>
01_Systems Development WP temp
01_Components
Operational
Relations
Domain
Relations
Data Model
MetaData
Stakeholders
Structure
system of interest
system of interest
Zoom
Documentation
Properties
Selection
Tools
Common
Note
Comment
Problem
Rationale
Element Gr...
Constraint
Block Definiti...
Package
Block
Interface B...
Flow Speci...
Constraint...
Domain
Internal Block...
Requirements...
Requirement
Extende...
Satisfy
Derive
Copy
Trace
Information Fl...
Use Case Dia...
Profiling Mec...
system of interest Ope...
100%
package Domain[_system of interest_ Operational Domain]
«block»
system of interest Operational Domain
«block»
JPL Rules
«block»
Stakeholder
«block»
system of interest Mission
«block»
system of interest Software Developer
«block»
system of interest System of Interest
dSN
«block»
DSN
«block»
User
«block»
system of interest Concept
«block»
system of interest Real
Logged in as sherzig [twc.openmbee.org:8080]
206471
1940
oose. innovative informatik
GfSE Gesellschaft für Systems Engineering e.V. German Chapter of INCOSE
HOOD
TUM

MBSE Initiative – SE2 Challe

COOKBOOK FOR MBSE WITH SYSML

Issue 1

19/01/2011

SE2 Cookbook for MBSE with SysML Issue 1 19/01/2011 Page 15 of 120

comprehensive product tree may in theory be satisfied by automatically merging all existing product tree diagrams into a big one (remember, each sub-system contains recursively its product tree).

«ProductTreeDiagram»
bdd [Structure Aspect] ZEUS_Structure [ZEUS_ProductTree]
Modification date 8/21/10 3:19 PM
«physical»
ZEUS
ZEUS_Content
«Comment»
A typed standard port represents the physical connector since a flow port cannot have a structure. An associated flow specification represents the actual flow. Allocation is used to associate the two.
«block»
ThickRoundPlugM
«FlowSpecification»
MotorControl_fs

Figure 5 Product Tree of the ZEUS substructure

ZEUS is one of the evaluated phasing sensors (Figure 5) and is based on the modified Mach–Zehnder interferometer phasing sensor. It is mounted on a breadboard and consists of a shutter, a cover, a color filter wheel, a neutral density filter wheel, and a translation stage which carries a phase mask. Different phase masks can be moved to the focal position by means of a translation stage, able to move in the X and Y directions.

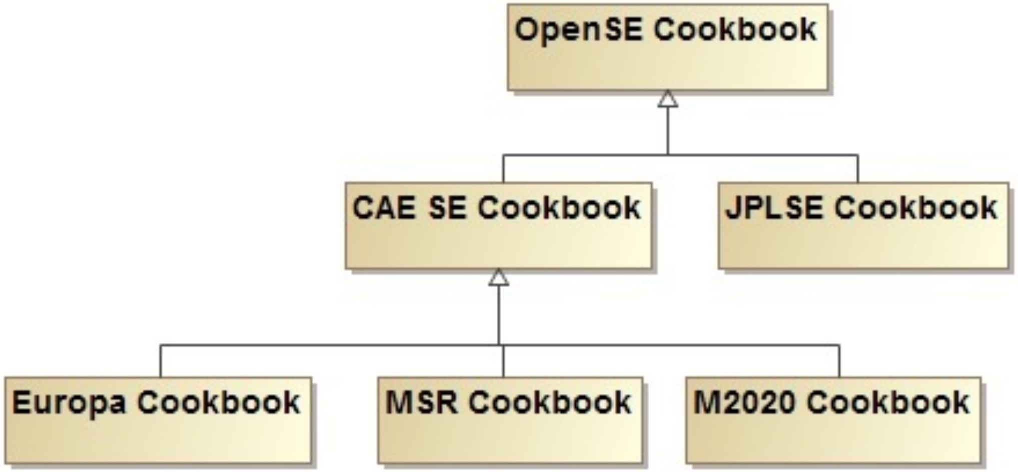
The two filter wheels located after the phase mask translation stage:

- A neutral Density Filter wheel: a set of 8 different neutral density filters are available
- An optical filter wheel: a set of 8 different optical filters centered on different wavelengths and with different bandwidths are available

Template models to be used by projects as a starting point, with recommended organization, model libraries, etc.

OpenSE Cookbook promotes re-use

- OpenSE Cookbook contributes to JPL institutional and project specific Cookbooks
- Project-independent modeling patterns as guidelines
- Project-specific modeling patterns for common modeling tasks



OpenSE Cookbook is used as reference

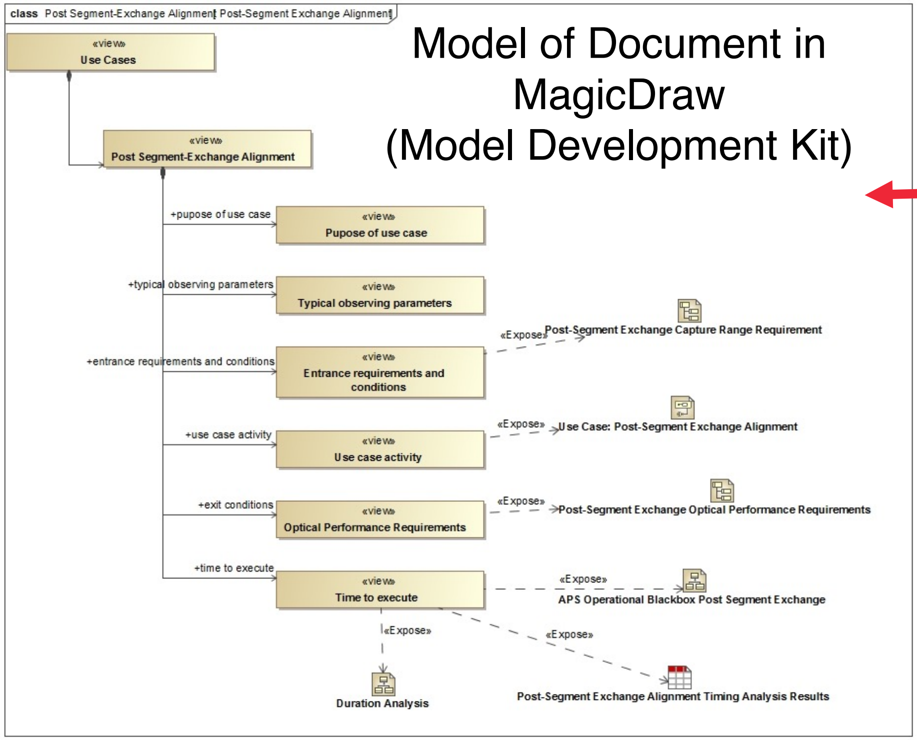
- OpenSE cookbook and TMT model used as reference model for the OMG SysML 2 standard
  - Demonstrate how SysML 2 will improve, simplify, change model wrt SysML 1.x
- Training material and knowledge transfer
- Promote standards and conventions
- Used by vendors as reference to test and evolve products

openmbee.org

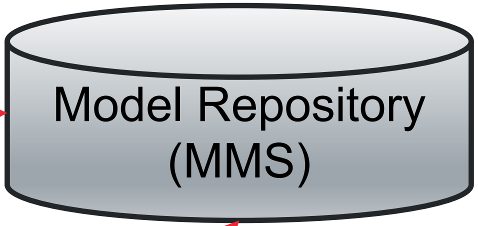
Open Model Based Engineering Environment

- OpenMBEE is a community for open-source modeling software and models
  - Number of open source software activities
  - Number of open source models
- JPL is a participant and adopter of OpenMBEE software and models
- Along with Boeing, Lockheed, OMG, NavAir, Ford, Stevens, GaTech, ESO
- Vendor participants
- ~200 members

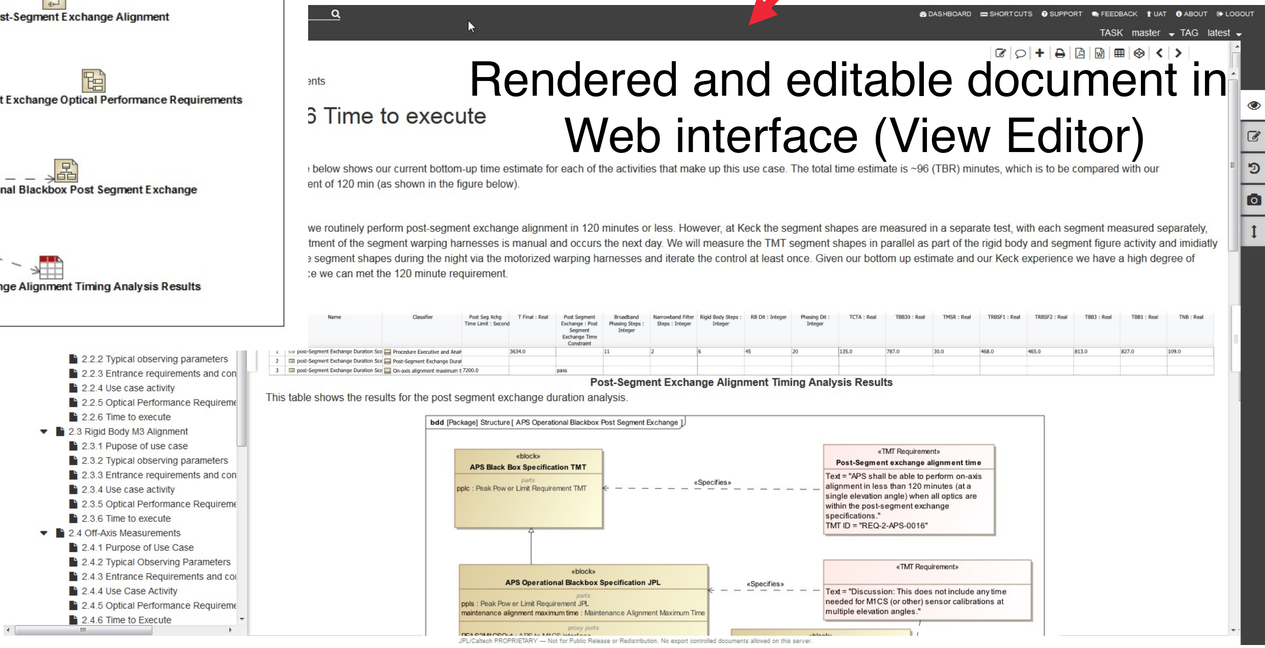
Core Integration of MMS, MDK, and VE


class Post Segment-Exchange Alignment Post-Segment Exchange Alignment
«view» Use Cases
«view» Post Segment-Exchange Alignment
+pupose of use case
«view» Pupose of use case
+typical observing parameters
«view» Typical observing parameters
+entrance requirements and conditions
«view» Entrance requirements and conditions
+use case activity
«view» Use case activity
+exit conditions
«view» Optical Performance Requirements
+time to execute
«view» Time to execute
«Expose» Post-Segment Exchange Capture Range Requirement
«Expose» Use Case: Post-Segment Exchange Alignment
«Expose» Post-Segment Exchange Optical Performance Requirements
«Expose» APS Operational Blackbox Post Segment Exchange
«Expose» Duration Analysis
«Expose» Post-Segment Exchange Alignment Timing Analysis Results

Model of Document in MagicDraw (Model Development Kit)



Model Repository (MMS)



Rendered and editable document in Web interface (View Editor)

ents

6 Time to execute

below shows our current bottom-up time estimate for each of the activities that make up this use case. The total time estimate is ~96 (TBR) minutes, which is to be compared with our ent of 120 min (as shown in the figure below).

we routinely perform post-segment exchange alignment in 120 minutes or less. However, at Keck the segment shapes are measured in a separate test, with each segment measured separately, tment of the segment warping harnesses is manual and occurs the next day. We will measure the TMT segment shapes in parallel as part of the rigid body and segment figure activity and imidiatly e segment shapes during the night via the motorized warping harnesses and iterate the control at least once. Given our bottom up estimate and our Keck experience we have a high degree of ce we can met the 120 minute requirement.

	Name	Classifier	Post Seg Xchg Time Limit : Second	T Final : Real	Post Segment Exchange : Post Segment Exchange Time Constraint	Broadband Phasing Steps : Integer	Narrowband Filter Steps : Integer	Rigid Body Steps : Integer	RB Dit : Integer	Phasing Dit : Integer	TCTA : Real	TBB30 : Real	TMSR : Real	TRBSF1 : Real	TRBSF2 : Real	TBB3 : Real	TBB1 : Real	TNB : Real
1	post-Segment Exchange Duration Sce	Procedure Executive and Anal		3634.0		11	2	6	45	20	135.0	787.0	30.0	468.0	465.0	813.0	827.0	109.0
2	post-Segment Exchange Duration Sce	Post-Segment Exchange Durat																
3	post-Segment Exchange Duration Sce	On-axis alignment maximum t	7200.0		pass													

Post-Segment Exchange Alignment Timing Analysis Results

This table shows the results for the post segment exchange duration analysis.

bdd [Package] Structure [APS Operational Blackbox Post Segment Exchange]

«block» APS Black Box Specification TMT
parts
pplc : Peak Power Limit Requirement TMT

«Specifies»

«TMT Requirement» Post-Segment exchange alignment time
Text = "APS shall be able to perform on-axis alignment in less than 120 minutes (at a single elevation angle) when all optics are within the post-segment exchange specifications."
TMT ID = "REQ-2-APS-0016"

«block» APS Operational Blackbox Specification JPL
parts
ppls : Peak Power Limit Requirement JPL
maintenance alignment maximum time : Maintenance Alignment Maximum Time
proxy ports

«Specifies»

«TMT Requirement»
Text = "Discussion: This does not include any time needed for M1CS (or other) sensor calibrations at multiple elevation angles."

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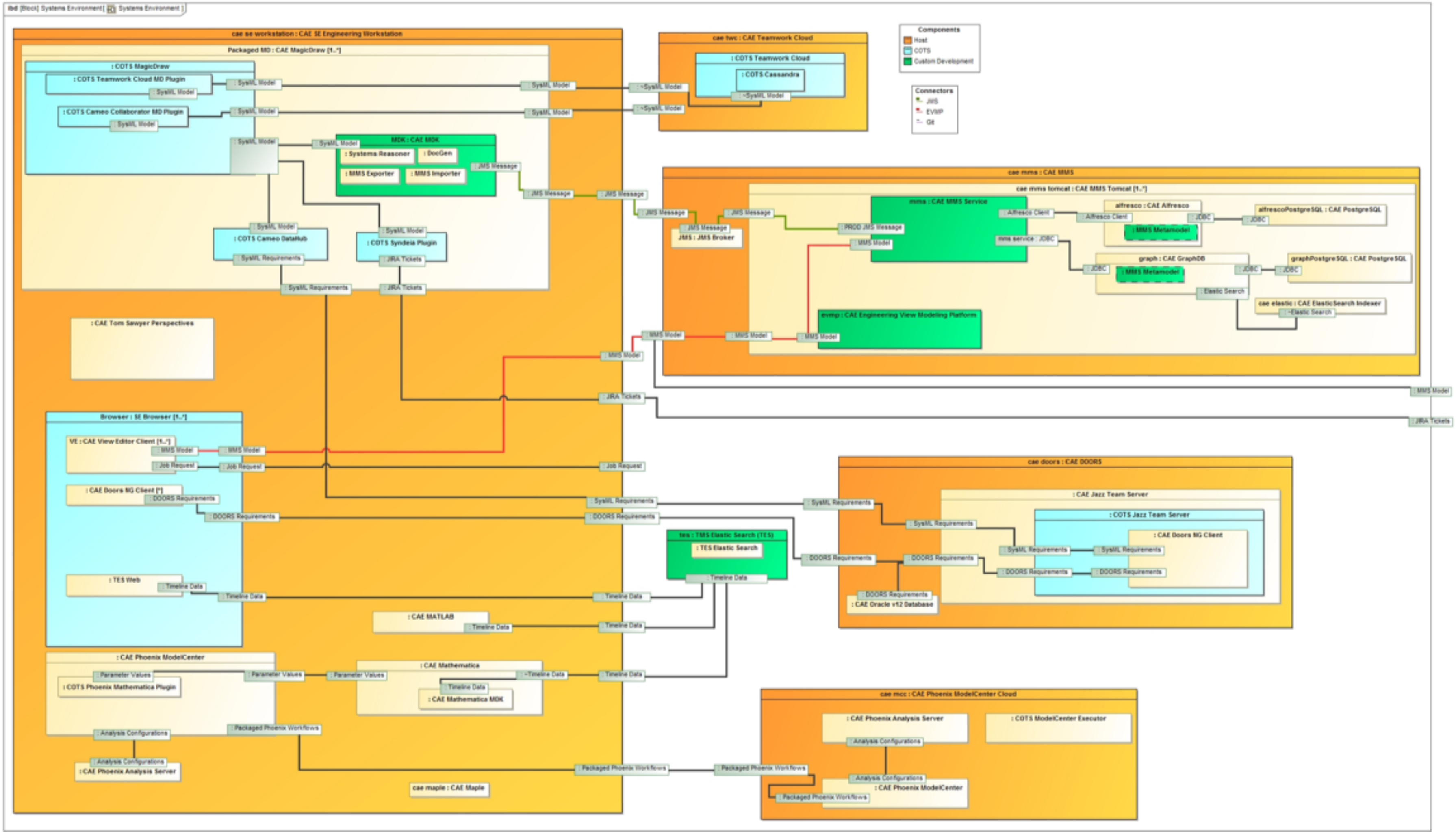
2.2.2 Typical observing parameters
2.2.3 Entrance requirements and con
2.2.4 Use case activity
2.2.5 Optical Performance Requireme
2.2.6 Time to execute
2.3 Rigid Body M3 Alignment
2.3.1 Pupose of use case
2.3.2 Typical observing parameters
2.3.3 Entrance requirements and con
2.3.4 Use case activity
2.3.5 Optical Performance Requireme
2.3.6 Time to execute
2.4 Off-Axis Measurements
2.4.1 Purpose of Use Case
2.4.2 Typical Observing Parameters
2.4.3 Entrance Requirements and co
2.4.4 Use Case Activity
2.4.5 Optical Performance Requireme
2.4.6 Time to Execute

Interactions Within CAE Systems Environment


ibd [Block] Systems Environment [Systems Environment]
cae se workstation : CAE SE Engineering Workstation
Packaged MD : CAE MagicDraw [1..*]
: COTS MagicDraw
: COTS Teamwork Cloud MD Plugin
: SysML Model
: COTS Cameo Collaborator MD Plugin
MDK : CAE MDK
: Systems Reasoner
: DocGen
: MMS Exporter
: MMS Importer
: JMS Message
: COTS Cameo DataHub
: SysML Requirements
: COTS Syndeia Plugin
: JIRA Tickets
: CAE Tom Sawyer Perspectives
Browser : SE Browser [1..*]
VE : CAE View Editor Client [1..*]
: MMS Model
: Job Request
: CAE Doors NG Client [*]
: DOORS Requirements
: TES Web
: Timeline Data
: CAE MATLAB
: CAE Phoenix ModelCenter
: Parameter Values
: COTS Phoenix Mathematica Plugin
: Analysis Configurations
: Packaged Phoenix Workflows
: CAE Phoenix Analysis Server
: CAE Mathematica
: ~Timeline Data
: CAE Mathematica MDK
cae maple : CAE Maple
cae twc : CAE Teamwork Cloud
: COTS Teamwork Cloud
: COTS Cassandra
: ~SysML Model
Components
🟧 Host
🟦 COTS
🟩 Custom Development
Connectors
JMS
EVMP
Git
cae mms : CAE MMS
JMS : JMS Broker
cae mms tomcat : CAE MMS Tomcat [1..*]
mms : CAE MMS Service
PROD JMS Message
: Alfresco Client
mms service : JDBC
alfresco : CAE Alfresco
: JDBC
: MMS Metamodel
alfrescoPostgreSQL : CAE PostgreSQL
graph : CAE GraphDB
graphPostgreSQL : CAE PostgreSQL
: Elastic Search
cae elastic : CAE ElasticSearch Indexer
: ~Elastic Search
evmp : CAE Engineering View Modeling Platform
tes : TMS Elastic Search (TES)
: TES Elastic Search
cae doors : CAE DOORS
: CAE Jazz Team Server
: COTS Jazz Team Server
: CAE Doors NG Client
: CAE Oracle v12 Database
cae mcc : CAE Phoenix ModelCenter Cloud
: CAE Phoenix Analysis Server
: COTS ModelCenter Executor
: CAE Phoenix ModelCenter

Managed Excel

Managed Excel in a collaborative environment

Summary & Conclusions

- JPL is successfully applying MBSE with SysML to numerous projects - large and small – over different life cycle phases
- Clear benefits: early verification, consistency, less ambiguity
- There has been tremendous progress in tools and methods in the past decade – and we're only just starting
  - Many lessons learned, tools, techniques integrated from MBSE practice
  - Strong developments in methodology and theory
- Magnitude of paradigm shift still leads to skepticism and adoption challenges ➔ transition inevitable, but slow

Acknowledgements

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

The TMT Project gratefully acknowledges the support of the TMT collaborating institutions. They are the Association of Canadian Universities for Research in Astronomy (ACURA), the California Institute of Technology, the University of California, the National Astronomical Observatory of Japan, the National Astronomical Observatories of China and their consortium partners, and the Department of Science and Technology of India and their supported institutes. This work was supported as well by the Gordon and Betty Moore Foundation, the Canada Foundation for Innovation, the Ontario Ministry of Research and Innovation, the National Research Council of Canada, the Natural Sciences and Engineering Research Council of Canada, the British Columbia Knowledge Development Fund, the Association of Universities for Research in Astronomy (AURA) and the U.S. National Science Foundation.

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- Analyzing the Operational Behavior of the Alignment and Phasing System of the Thirty Meter Telescope using SysML Sebastian J. I. Herzig, Robert Karban, Gelys Trancho, Frank G. Dekens, Nerijus Jankevicius, and Mitchell Troy, Adaptive Optics for Extremely Large Telescopes, Tenerife, 2017
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- Open Source Engineering Environment: https://www.openmbee.org
- https://www.jpl.nasa.gov/spaceimages/

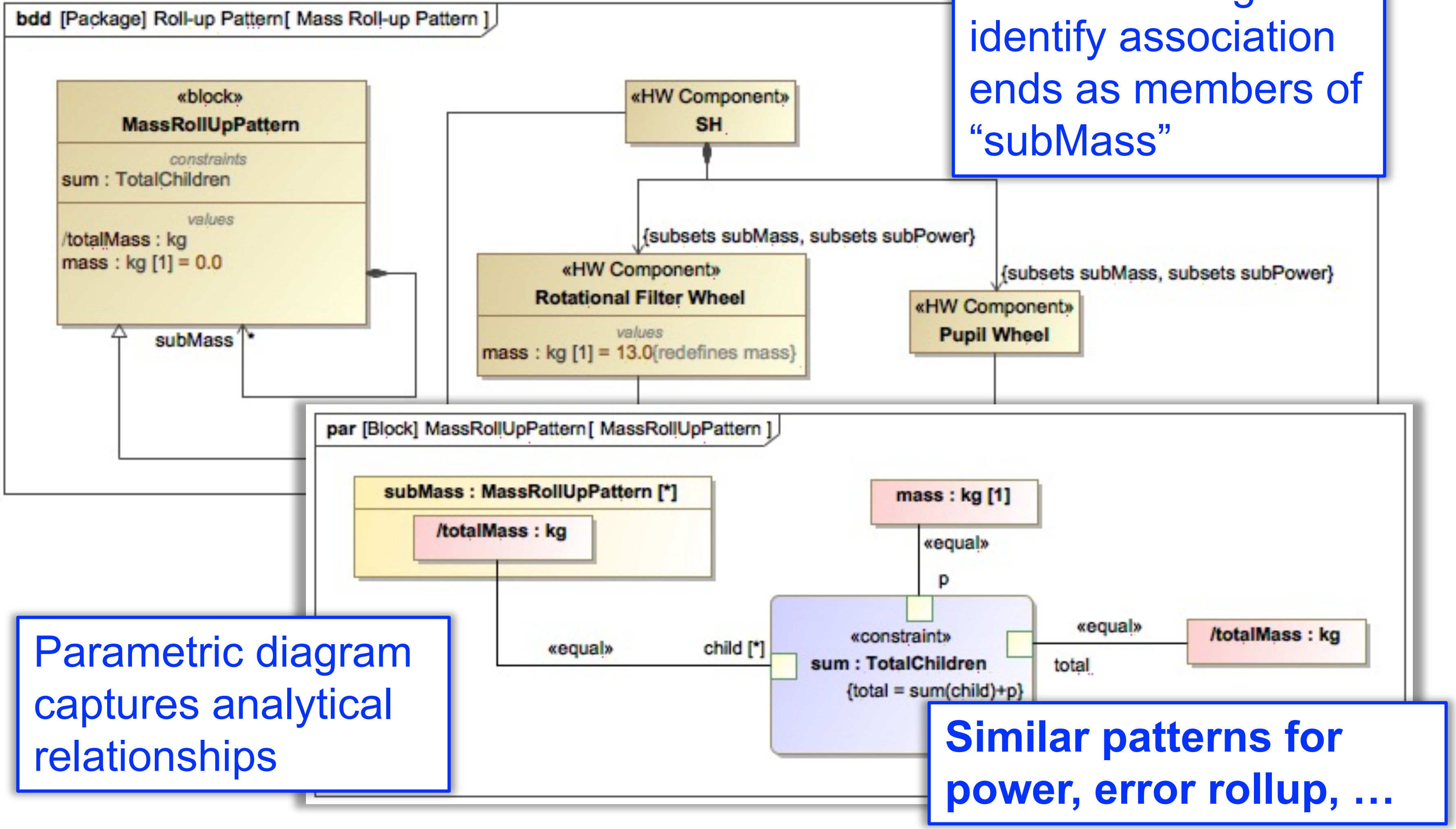
Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov

BACKUP SLIDES

“Static” Rollup Analyses – Example: Mass

Thirty Meter Telescope



Use subsetting to identify association ends as members of “subMass”

Parametric diagram captures analytical relationships

Similar patterns for power, error rollup, …

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov